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PRELIMINARY LAUNCH ABORT STUDY FOR APOLLO MISSION D/CSM-103/LM-3

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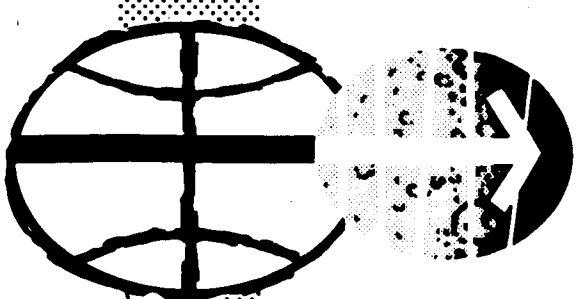

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

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MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
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1. INTRODUCTION

1.1 Purpose

This document presents the results of a preliminary launch abort study defining the abort regions for Apollo Mission D/CSM-103/LM-3. Nominal trajectory data and abort parameters are presented for the launch phase. These data are provided to assist the crew in monitoring realistic values of certain key parameters during simulator training. The abort modes included in this document are defined to provide optimum coverage of the launch trajectory in order to return the command module (CM) and crew to earth following a contingency situation. The results contained herein are preliminary in nature and will be updated in the operational Apollo Mission D/CSM-103/LM-3 launch abort plan.

1.2 Scope

This document has been restricted to the analysis of Apollo Mission D aborts from tower jettison through insertion. The majority of this report has been directed towards generating data for aborts from the nominal launch trajectory. Several inertial velocity versus inertial flight-path angle figures were obtained by assuming off-nominal inertial flight-path angles at abort initiation. The following lines were generated using off-nominal flight-path angles at abort initiation:

a) Mode II 16-g maximum entry load factor limit lines

b) Mode II, Mode III, and Fixed ΔV 100-second time-of-free-fall (T_{ff}) limit lines

c) Mode II constant landing range lines

d) Mode III and Mode IV constant service propulsion system (SPS) burn-time lines

The Mode IV envelope was defined using off-nominal inertial flight-path angles, altitudes, and pitch attitude alignments.

2. MISSION D DATA

2.1 Spacecraft and Launch Trajectory Data

The preliminary CM and command service module (CSM) weights and propulsion data used in the abort simulations are listed in Table I and were obtained from References 1 and 2. The launch vehicle state vectors used in generating most of the trajectory data were obtained from References 3 and 4 which contain the AS-503 launch vehicle reference trajectory. Since the AS-503 launch vehicle operational trajectory for the boilerplate configuration (Reference 5) may be more representative of the final ascent-to-orbit profile for Apollo Mission D, some data were generated using this launch trajectory and are included in this document for comparison purposes. Table II presents the aerodynamic coefficients used in this study as functions of Mach number (Reference 6). Table III contains the sequence of significant events of the launch trajectory (Reference 3) from lift-off to insertion as a function of ground elapsed time.

2.2 Launch Site Inertial (LSI) Reference System

The LSI reference system used in this document to define the attitude angles is a right-handed orthogonal coordinate system centered at the launch site. The positive X-axis extends upward along the astronomical vertical at lift-off and the negative Z-axis is directed downrange along the flight azimuth and lies in the horizontal plane. The positive Y-axis completes the right-handed system and lies on the left orthogonal of the flight azimuth. All attitude data presented in this report are referenced to the LSI system, which is shown in Figure 1.

2.3 Atmosphere

The atmosphere used in this study is the United States standard atmosphere model, 1962 (Reference 7). The atmosphere was simulated from 300,000 feet altitude to drogue chute deployment (23,500 feet altitude) which is considered splashdown. Since the Real Time Computer Complex (RTCC) considers 400,000 feet altitude as the entry interface during abort simulations, some trajectory data were provided at that altitude.

2.4 Computer Program and Input Data

The multiple vehicle N-stage (MVNS) trajectory simulation program was used to generate the data presented in this report. A detailed description of the MVNS can be found in Reference 8. The earth constants, conversion factors, and geodetic data in the trajectory simulation program were extracted from Reference 9.

3. ABORT MODE DEFINITIONS AND PROCEDURES

3.1 CSM/S-IVB (or S-II) Separation Sequence

The procedure for separating the CSM from the S-IVB or S-II launch vehicle is the same for all launch phase aborts except Mode I which utilizes the launch escape tower (LET) to separate the CM from the launch vehicle. Modes II, III, and IV, Fixed ΔV, and Apogee Kick aborts are initiated by turning the translation hand controller (THC) counterclockwise to cut off the launch booster. Tailoff of the S-II and S-IV boosters were simulated based on the data presented in Reference 10. Three seconds after S-IVB shutdown, the CSM separates from the booster with the four service module (SM) reaction control system (RCS) jets thrusting. The RCS burns continuously for 21 seconds to provide a safe separation distance from the S-IVB. At this point, 24 seconds after abort initiation, the Mode III, Mode IV, Fixed ΔV, and Apogee Kick procedures become different from those of Mode II (Table IV).

3.2 Mode I

Mode I abort capability exists from lift-off until LET jettison occurs at approximately 3 minutes and 6 seconds ground elapsed time (g. e. t.). These aborts utilize the LET to separate the CM from the launch vehicle and are characterized by high accelerations induced by the launch escape motor and high aerodynamic forces and wind effects induced by the atmosphere at low altitudes. Figure 2 shows the launch escape vehicle (LEV) configuration used in Mode I aborts. Mode I launch abort data are generated and documented separately; therefore these data are not included in this document.

3.3 Mode II

The abort Mode II regime is defined to begin at the time of LET jettison and to continue until the full-lift landing point is at the Atlantic Discrete Recovery Area (ADRA). The ADRA is defined to be 3200 nautical miles downrange from the Cape at the half-lift landing point. The full-lift landing point occurs along the Atlantic Continuous Recovery Area (ACRA) until the ADRA is reached. Twenty-four seconds after booster shutdown (CSM/S-IVB or S-II separation sequence), the CSM begins orienting to the CM/SM separation attitude. The CM separates from the SM as soon as possible after the X-translation RCS burn and begins orienting for atmospheric entry. One hundred seconds after abort initiation, the CM is oriented for a full-lift entry beginning at 300, 000 feet altitude above the Fischer reference ellipsoid.

The upper boundary of Mode II is defined by the upper 16-g load factor limit line. The lower boundary is defined by the 100-second T_{ff} limit line, the lower 16-g maximum load factor limit line, or both.

3.4 Mode III

When the full-lift landing point becomes 3200 nautical miles downrange from the launch pad, the Mode II regime ends, and the Mode III procedure for aborts to the ADRA is followed. The procedure for Mode III is the same as Mode II until cutoff of the four SM RCS jets at 24 seconds after abort initiation. At this point in a Mode III abort, the CSM begins orienting for the RCS ullage. By 110 seconds after S-IVB shutdown, the CSM X-axis is aligned heads up and 31.7 degrees below the line of sight to the horizon, and the four SM RCS jets are ignited and are burned continuously for 15 seconds. At 125 seconds after S-IVB shutdown, the CSM X-axis is aligned 31.7 degrees below the line of sight to the horizon and the SPS is ignited (Figure 3). The SPS retrograde burn is executed via the stabilization and control system (SCS) ΔV mode which maintains the inertial attitude of the thrust vector during the burn. After the SPS burn the CM separates from the service module and begins orienting for a full-lift atmospheric entry. At 0.2 g the CM is reoriented for a half-lift entry (bank South 55 degrees) to an altitude of 23,500 feet. Entry begins at an altitude of 300,000 feet above the Fischer reference ellipsoid.

3.5 Fixed ΔV

The Fixed ΔV procedure is designed to cover the near and postinsertion region where a Mode III abort cannot be performed. This abort mode uses the same SPS burn orientation (Figure 3) as Mode III. The sequence of events is the same as Mode III except for the ignition time of the 15 second RCS ullage and the SPS retrograde burn. Instead of igniting the SPS at 125 seconds after S-IVB shutdown, the SPS ignition time is delayed to satisfy the four following constraints. First, the landing point must be in the Indian Ocean Recovery Area (IORA), which is 8800 nautical miles downrange from the launch site. Second, after SPS cutoff, there must be at least 100 seconds of predicted time of free fall to 300,000 feet altitude (as computed by the Apollo guidance computer). Third, the fixed SPS retrograde ΔV must be 600 feet per second. Fourth, the SPS ignition must be greater than 125 seconds from abort initiation.

3.6 Mode IV

Mode IV exists when the SPS capability of inserting the CSM into a contingency orbit and deorbiting exists. During a Mode IV abort, the CSM begins orienting for a posigrade burn after the CSM/S-IVB or S-II separation sequence. By 110 seconds after S-IVB shutdown, the CSM X-axis is aligned 31.7 degrees above the line of sight to the horizon, and the four SM RCS jets are ignited and are burned continuously for 15 seconds. One hundred twenty-five seconds after abort initiation, the CSM X-axis is aligned at 31.7 degrees above the line of sight to the horizon (Figure 3). At this time the SPS burn is initiated and is continued until predicted perigee reaches an altitude of 75 nautical miles. The SPS burn is executed via the SCS ΔV mode which maintains the inertial orientation of the thrust vector during the burn.

The Mode IV regime, by definition, begins when the SPS is able to insert the CSM into an orbit with a perigee altitude of at least 75 nautical miles. When the instantaneous perigee altitude is 75 nautical miles at S-IVB shutdown, Mode IV ends because the SPS ΔV required is zero.

4. RESULTS

4.1 Nominal Trajectory Data

Nominal trajectory data obtained from Reference 3 are presented in graphical form to provide a pictorial representation of the ascent profile. Figure 4 presents the altitude (over an oblate earth), altitude rate, and dynamic pressure as functions of ground elapsed time along the nominal trajectory. Table V contains the dynamic pressure that would be experienced by the launch vehicle as a function of ground elapsed time. Table VI contains a listing of values of the standard display and keyboard panel (DSKY) parameters - inertial velocity, altitude (over a spherical earth based on pad radius), altitude rate, altitude at perigee, altitude at apogee, time of free fall to a 300,000-foot altitude, and target miss distance (SPLERROR) - as functions of ground elapsed time from lift-off. These parameters will be monitored by the crew during simulations and during the actual flight and will be used to initiate and perform aborts in a no voice situation. Figure 5 depicts the DSKY, the COLOSSUS Program 11 nominal displayed parameters, and the procedural logic required to obtain the display of other variables. Figure 6 is a plot of inertial velocity and inertial flight-path angle in terms of ground elapsed time. Figure 7 presents the launch vehicle pitch attitude (referenced to LSI) with respect to ground elapsed time. Table VII contains the launch vehicle pitch, yaw, and roll attitudes along the nominal trajectory as functions of ground elapsed time.

Figures 8 and 9 compare the AS-503 launch vehicle reference trajectory (Reference 3) and the launch vehicle operational flight trajectory for the boilerplate configuration (Reference 5) in terms of altitude, range, inertial flight-path angle, and inertial velocity. It should be noted that there is a marked similarity between the two profiles.

In Figure 10, the various abort modes are displayed on an inertial velocity versus ground elapsed time plot of the nominal trajectory. During the interval designated on the figure for each abort mode, such an abort procedure can be performed without violating the particular abort mode constraints.

4.2 Mode II Results

The Mode II procedure covers a major part of the launch phase (from 3 minutes and 6 seconds, g.e.t. to 10 minutes and 18 seconds, g.e.t.). The maximum entry load factor and the full-lift landing range are shown in Figure 11 and Table VIII as functions of ground elapsed time along the nominal trajectory. Figure 12 contains the full-lift landing range line as a function of inertial velocity along the nominal trajectory.

Figure 13 shows the full-lift 16 g constant maximum entry load factor limit line and the minimum sequence limit line (100 seconds time of free fall) which define the upper and lower boundaries of Mode II.

The time of free fall at abort to 300,000 feet altitude is presented in Figures 14 and 15 as a function of ground elapsed time and full-lift landing range, respectively. Figure 14 and Table IX also include the pitch attitude angle at atmospheric entry (300,000-foot altitude).

The ground elapsed times for an atmospheric entry at 400,000 feet and drogue chute deployment at 23,500 feet are presented in Table X for Mode II aborts from the nominal trajectory. In Figure 16, the inertial velocity and inertial flight-path angle at a 400,000-foot altitude that result in 16 g's as the maximum entry load factor are shown for both a zero-lift (bank angle equals 90 degrees) entry and a full-lift (bank angle equals zero degrees) entry.

Ionization, induced by aerodynamic heating, eliminates all very high frequency (VHF) communication with the CM during certain portions of the entry phase of the mission. Figure 17 and Table XI show ground elapsed time at the entry and exit of the communication blackout region when contact with the crew is not possible. Although VHF data were used for this simulation, good agreement with the actual S-band was obtained. Table XII contains a listing of discrete times and spacecraft orientations at a 400,000-foot entry interface altitude during nominal Mode II aborts.

In Figure 18, constant range lines are shown for a full-lift entry to a 7100-nautical mile downrange landing point and a zero-lift entry to a 3500-nautical mile downrange landing point. Also included are instantaneous 35- and 75-nautical mile perigee lines. These perigees are used to describe conditions of safe entry and safe orbit respectively.

4.3 Mode III Results

The Mode III region begins at approximately 10 minutes and 18 seconds, g.e.t., and continues until 11 minutes and 23 seconds, g.e.t. Because Mode III aborts employ CM half-lift entries as opposed to full-lift entries for Mode II aborts, early abort times in the Mode III region require no SPS burn and will land short of the ADRA. The Mode III region requiring an SPS retrograde burn, begins at 10 minutes and 30 seconds, g.e.t., and ends at 11 minutes and 23 seconds when the time of free fall remaining at the end of the burn is less than 100 seconds.

Mode III aborts from the nominal launch trajectory do not cause the crew to experience excessive entry deceleration loads. The time of free fall to 300,000 feet and the entry deceleration experienced are shown in Figure 19 and Table XIII as functions of ground elapsed time of abort. Ground communication with the spacecraft is lost during entry following Mode III aborts, as was the case in the Mode II region. Figure 20 and Table XIV indicate that there exists a period of approximately 2 minutes and 14 seconds during which VHF communications with the crew is highly improbable due to ionization of the atmosphere. Table XV contains a listing of discrete times and spacecraft orientations at the 400,000-foot entry interface altitude during nominal Mode III aborts. Table XVI and Figure 21 show the spacecraft pitch attitude angle at SPS ignition.

Figure 22 presents a plot of SPS ΔV expended and ground elapsed time of abort versus SPS burn time for Mode III and Mode IV aborts. The Mode III tabular data appear in Table XVII. In Figure 23, the Mode III region is shown on an inertial flight-path angle versus inertial velocity plot. This region is defined by the Mode II/Mode III boundary line where Mode III aborts can first be performed and by the 100-second time-of-free-fall limit line marking the end of the Mode III region. Figure 23 also contains constant SPS ΔV lines throughout the region as well as two lines defining the Fixed ΔV abort region. These two lines are discussed in the next section.

Figure 24 contains constant landing range lines for premature SPS shutdowns during nominal Mode III launch aborts. The last time that an Atlantic landing is possible is defined by a zero-lift entry to the west coast of Africa (3500 nautical miles downrange). The first time that an Indian Ocean landing can be made is defined by a full-lift entry to the east coast of Africa (7100 nautical miles downrange). The shaded area indicates the combination of ground elapsed time at abort and premature SPS cutoff that would result in an African impact regardless of the bank angle at entry. The short line in the extreme right-hand corner represents the premature SPS cutoff that would result in a 35-nautical mile perigee. Also included is the line illustrating the SPS burn required for Mode III aborts from the nominal trajectory with a half-lift entry to land 3200 nautical miles downrange.

Figure 24 also contains a 100-second T_{ff} line which was obtained without any consideration of the resulting landing range. Note that this constant T_{ff} line crosses the nominal Mode III SPS burn timeline at 11 minutes and 23 seconds and by definition represents the end of Mode III capability from the nominal launch trajectory.

As Figures 19, 23, and 24 show, near insertion the time of free fall after the SPS burn to a 300,000-foot altitude becomes less than the 100-second limit required to reorient the CSM for separation and entry. The two main reasons for this problem are the heavy CSM and the large downrange distance at abort. The latter requires a very large retrograde burn, and the former reduces the efficiency of the SPS burn. It should be noted, however, that Mode IV capability exists and is prime in this region.

4.4 Fixed ΔV Results

The Fixed ΔV abort capability region begins on the nominal at the earliest time that a Fixed ΔV can be performed (maximum time delay). This time is defined by delaying SPS ignition to satisfy the 8800 nautical mile landing point and the 100-second time-of-free-fall constraints. The ground elapsed time of abort corresponding to the maximum delay time for Apollo Mission D on the nominal launch trajectory is 11 minutes and 30 seconds with SPS ignition occurring at 35 minutes 35.86 seconds, g.e.t. For overspeed trajectories, a Fixed ΔV abort can be performed until the time between S-IVB cutoff and SPS ignition is equal to 2 minutes and 5 seconds (minimum time delay). The velocity for this overspeed case at abort is 25,930 feet per second. Figure 23 contains the Fixed ΔV region.

Assuming a nominal insertion into the parking orbit, the latest that a Fixed ΔV abort can be performed corresponds to a ground elapsed time at SPS ignition of 30 minutes and 27.3 seconds. Nominal Fixed ΔV abort data are presented in Table XVIII and consist of ground elapsed time, inertial velocity, and altitude rate at abort, the delay time to SPS ignition, the pitch attitude at SPS ignition, the pitch attitude at 300,000 feet, and the time of free fall remaining at the end of the SPS burn. Table XIX displays ground elapsed time at the entry and exit of the VHF communications blackout region for representative Fixed ΔV nominal aborts. Flight crew simulations data showing spacecraft orientations and time to the 400,000-foot entry interface altitude and 23,500-foot altitude at drogue chute deployment appear in Table XX.

Since the Fixed ΔV abort capability region does not overlap the Mode III capability region, there exists a gap of approximately 7 seconds along the nominal trajectory in Figure 23 where a suborbital abort cannot be performed without violating time of free fall or landing range constraints as currently defined at the time of this data generation. It should be noted, however, that Mode IV capability exists and is prime in this region.

4.5 Mode IV Results

The earliest time that a Mode IV procedure can be performed (considering pitch errors) is 10 minutes and 6 seconds, g.e.t. Figure 22 shows ground elapsed time at abort and the amount of SPS ΔV expended as functions of SPS burn time for Mode IV aborts. The corresponding data are in Table XXI. Figure 25 and Table XXII contain the pitch angle at SPS ignition. This procedure is prime wherever the capability exists.

The contingency orbital insertion (COI) capability analysis is presented in Figure 26. The theoretical COI regime was generated assuming nominal conditions at abort, the correct pitch attitude at SPS ignition, and is well within the SPS ΔV available. The effects on this region of either a plus or minus 5-degree pitch error at SPS ignition, or a plus or minus 5-nautical mile altitude error at time of abort are included in this figure.

Figure 27 displays the Mode IV region that is bounded by the negatively sloped segments of the minus 5-degree pitch error line and the positively sloped segment of the plus 5-degree pitch error line from Figure 26. A plus and minus 5-degree pitch error bias was used to insure capability within the region even with an attitude error. This error cannot be accounted for in the RTCC ΔV calculation. Altitude deviations were not considered in the bias but are considered in the RTCC calculation of ΔV required. Also included are the constant SPS ΔV lines illustrating the amount of SPS ΔV required to achieve a 75-nautical mile perigee and constant apogee lines showing the type of orbit that would result.

The maximum SPS ΔV required for this modified Mode IV region is nearly 2500 feet per second, which is considerably less than the approximately 9000 feet per second SPS ΔV available. Therefore Mode IV is not limited by any SPS ΔV considerations.

In this document, the SPS ΔV to achieve a 75-nautical mile perigee is presented. In an actual abort situation, the ΔV will be padded. Near the limits of Mode IV capability, such a pad could cause the resulting perigee to decrease to a value of less than 75 nautical miles. For the effects of a pad on Mode IV aborts from Saturn I-B trajectories (indicating trends for Saturn V trajectories), see Reference 11.

In Figure 28, the posigrade burns that result in a zero-lift entry to 3500 nautical miles, a full-lift entry to 7100 nautical miles, and 35- and 75-nautical mile perigee lines are shown. The shaded area in Figure 28 indicates the premature SPS shutdown during a posigrade burn that would result in an African landing regardless of the bank angle chosen at entry.

Figure 29 presents the regions and boundaries for Modes II and III, Fixed ΔV, and Mode IV aborts. The contingency insertion regime and the altitude and pitch attitude dispersions from Figure 26 are contained in Figure 29. The aborts initiated at conditions to the left of the Mode II/ Mode III line would result in full-lift (Mode II) landing points falling short of the ADRA. Aborts initiated with conditions to the right of this line require an SPS retrograde burn and a half-lift entry to land at the ADRA. The Mode III region continues to the 100-second T_{ff} limit line where the Mode III region ends. The area to the right of the Apogee Kick line defines a region where the resulting apogee following an S-IVB shutdown occurs after the Canary Island tracking station has acquired the spacecraft. This zone is defined so that any spacecraft burn to be performed at apogee can be relayed to the crew via the Canary Island station. The final lines depict the Fixed ΔV abort region, where delayed fixed SPS retrograde burns will result in a spacecraft landing in the IORA.

5. CONCLUDING REMARKS

The data presented herein indicate that continuous abort capability exists from the nominal trajectory. Continuous direct return-to-earth capability was not found to be possible based on the abort mode definitions included here. As a result of studies, conducted after the generation of the herein included data, a decision has been reached to change the ADRA to a range of 3350 nautical miles and to delete the Fixed ΔV abort mode requirement. These changes increase the Mode III capability beyond the nominal insertion point. It should, however, be noted that within this region Mode IV capability exists and is the prime mode.

Altitude sensitivity studies are not included within these data. Data presenting altitude and attitude sensitivities for Saturn I-B trajectories are documented in Reference 11. These data, although not calculated directly for Saturn V trajectories, can be used to determine trends and to obtain approximations of the effects of similar deviations on Saturn V data.

Table I. Preliminary Spacecraft Data

CM Weight = 13,065 (lb)

CSM Weight (including SPS tanked propellant) = 59,133 (lb)

RCS Thrust = 398.4 (lb)

RCS Propellant Flow Rate = 1.428 (lb/sec)

SPS Engine Thrust = 20,000 (lb)

SPS Propellant Flow Rate = 63.51 (lb/sec)

SPS Engine I_{SP} = 313.4 (sec)

SPS Usable Propellant = 34,608 (lb)

Total SPS ΔV Available = 8,917 (ft/sec)

Table II. Block II Spacecraft Aerodynamic Data*

X_{CG} = 1042.8 Y_{CG} = -0.5 Z_{CG} = 5.3

Mach Number, M (nd)	Lift Coefficient, C_L (nd)	Drag Coefficient, C_D (nd)	Lift-to-drag Ratio, L/D (nd)	Trim Angle of Attack, α_T (deg)
0.00	0.2073	0.8587	0.2414	168.91
0.40	0.2073	0.8587	0.2414	168.91
0.70	0.2244	0.9301	0.2413	166.48
0.90	0.2909	1.0798	0.2694	163.77
1.10	0.4469	1.2020	0.3718	157.76
1.20	0.4395	1.1870	0.3703	157.65
1.35	0.5160	1.3054	0.3953	156.47
1.65	0.5191	1.2936	0.4013	155.48
2.00	0.5086	1.3134	0.3872	155.50
2.40	0.4808	1.2849	0.3742	156.11
3.00	0.4538	1.2635	0.3591	156.48
4.00	0.4169	1.2517	0.3331	158.18
6.00	0.3584	1.3284	0.2698	162.15
100.00	0.3584	1.3284	0.2698	162.15

*Beginning of mission aerodynamics

Table III. Sequence of Events Along the Nominal Launch Trajectory*

Ground Elapsed Time (min:sec)	Events
0:00.000	First motion
1:17.250	Maximum dynamic pressure
2:19.316	S-IC inboard engine cutoff
2:20.000	Tilt arrest
2:30.623	S-IC thrust termination and S-IC/S-II separation
2:35.061	S-II at 90 percent thrust level
3:00.861	Jettison S-IC/S-II forward interstage
3:05.861	LES tower jettison
8:44.192	S-II thrust termination and S-II/S-IVB separation
8:49.942	S-IVB at 90 percent thrust level
8:56.341	Jettison S-IVB ullage cases
11:35.280	S-IVB thrust termination signal

*Based on the AS-503 Launch Vehicle Reference Trajectory

Table IV. Sequences of Events for Mode II, Mode III, Fixed ΔV, and Mode IV Launch Aborts

A. Mode II Sequence of Events

Time from S-IVB (or S-II) Shutdown (min:sec)	Event
0:00.00	S-IVB (or S-II) cutoff
0:01.85 (0:00.875 for S-II)	End of S-IVB (or S-II) tailoff
0:03.00	CSM/S-IVB (or S-II) separation, RCS direct ullage ON
0:24.00	RCS direct ullage OFF, coast to entry altitude, then B/A = 0.0 degree

B. Mode III (and Fixed ΔV) Sequence of Events

Time from S-IVB Shutdown (min:sec)	Event
0:00.00	S-IVB cutoff
0:01.85	End of S-IVB tailoff
0:03.00	CSM/S-IVB separation, RCS direct ullage ON
0:24.00	RCS direct ullage OFF, maneuver to retrograde attitude
1:50.00*	RCS direct ullage ON
2:05.00*	RCS direct ullage OFF, SPS thrust ON – SPS thrust OFF when IP equals 3200 n mi**. Coast to 300,000 feet then B/A = 0.0 degree to 0.2 g then B/A = 55.0 degrees

*Variable for fixed ΔV aborts

**SPS ΔV equals 600 ft/sec for fixed ΔV procedure, IP = 8800 n mi

Table IV. Sequences of Events for Mode II, Mode III, Fixed ΔV, and Mode IV Launch Aborts (Continued)

C. Mode IV (Contingency Orbit Insertion)

Time from S-IVB Shutdown (min: sec)	Event
0:00.00	S-IVB cutoff
0:01.85 (0:00.875 for S-II)	End of S-IVB(or S-II) tailoff
0:03.00	CSM/S-IVB separation, RCS direct ullage ON
0:24.00	RCS direct ullage OFF, maneuver to posigrade attitude
1:50.00*	RCS direct ullage ON
2:05.00*	RCS direct ullage OFF, SPS thrust ON, SPS thrust OFF when perigee equals 75 n mi

*Variable for Apogee Kick aborts; RCS direct ullage ON at 15 seconds prior to reaching apogee.

Table V. Dynamic Pressure

Ground Elapsed Time From Lift-off (min:sec)	Dynamic Pressure (lb/ft^2)
0:10	9.3
0:20	44.9
0:30	118.1
0:40	236.4
0:50	396.4
1:00	569.9
1:10	706.3
1:20	740.0
1:30	586.3
1:40	383.9
1:50	229.8
2:00	123.3
2:10	61.6
2:20	30.3
2:30	12.4
2:41	2.8
2:51	0.6
3:01	0.1
3:11	0.0

Table VI. Display and Keyboard Data from the Nominal Trajectory

Ground Elapsed Time from Lift-off (min:sec)	Inertial Velocity (ft/sec)	Altitude (Based on Pad Radius) (n mi)	Altitude Rate* (ft/sec)	Altitude at Perigee** (n mi)	Altitude at Apogee (n mi)	Time of Free Fall to 300,000 ft (min:sec)	Delta Range*** (n mi)
3:06	9,357.01	52.27	2717.37	-3217.82	75.705	-3:30.78	-2745.5
3:11	9,445.88	53.90	2435.46	-3211.24	77.704	-3:32.97	-2688.3
3:31	9,831.28	62.84	2162.33	-3183.28	81.149	-3:31.96	-2674.5
3:51	10,263.74	70.03	1898.62	-3156.18	90.179	-3:31.83	-2610.8
4:11	10,743.43	77.26	1645.30	-3114.92	91.201	-3:31.79	-2588.3
4:31	11,270.83	83.09	1403.94	-3073.31	92.059	-3:30.73	-2534.1
4:51	11,846.88	88.11	1175.76	-3025.55	94.830	-3:29.44	-2476.4
5:11	12,473.06	92.35	962.73	-2970.48	97.223	-3:28.11	-2414.5
5:31	13,151.53	95.86	766.88	-2906.61	99.259	-3:26.96	-2347.6
5:51	13,885.22	98.70	591.35	-2832.04	100.956	-3:26.26	-2274.5
6:11	14,678.03	100.93	439.18	-2744.25	102.344	-3:26.40	-2193.4
6:31	15,535.05	102.62	314.32	-2639.87	103.450	-3:27.83	-2102.0
6:51	16,462.84	103.85	203.92	-2514.28	104.311	-3:31.28	-1996.3
7:11	17,387.19	104.72	102.06	-2374.03	104.927	-3:35.78	-1881.0
7:31	18,274.86	105.21	34.23	-2223.44	105.267	-3:40.74	-1757.9
7:51	19,231.33	105.42	6.72	-2040.70	105.430	-3:50.02	-1607.5
8:11	20,265.39	105.47	27.62	-1815.04	105.478	-4:06.66	-1412.6
8:31	21,388.40	105.52	27.14	-1529.93	105.527	-4:37.30	-1164.9
8:51	22,217.89	105.68	-49.26	-1286.75	105.685	-5:08.20	-920.7
9:11	22,583.46	105.64	-11.06	-1169.57	105.668	-5:14.21	-792.7
9:31	22,961.18	105.38	-152.82	-1041.70	105.549	-5:23.79	-644.2
9:51	23,350.79	104.93	-175.35	-901.81	105.314	-5:39.20	-463.2
10:11	23,752.25	104.55	-175.87	-748.16	104.995	-6:03.86	-234.5
10:31	24,165.54	103.87	-151.93	-578.71	104.060	-6:45.07	-83.4
10:51	24,376.63	103.22	-151.93	-391.93	103.460	-8:01.06	567.3
11:11	25,027.67	102.93	-101.34	-181.85	103.210	-11:59.93	1183.4
11:26	25,363.20	102.62	-44.27	-8.79	102.980	-19:40.36	3623.4
11:31	25,476.56	102.60	-21.34	52.36	102.800	-59:59.00	-1798.0

*Minus sign indicates that the inertial flight-path angle is negative.

**Minus sign indicates that perigee occurs below the surface of the earth.

***Minus sign indicates that the AGC predicted half-lift landing point is less than 3200 nautical miles downrange.

Table VII. Spacecraft Pitch, Yaw, and Roll Attitudes Along the Nominal Trajectory*

Ground Elapsed Time from Lift-off (min:sec)	Pitch (deg)	Yaw (deg)	Roll (deg)
0:00	0.00	0.00	-18.00
0:10	0.00	0.00	-18.00
0:20	1.58	0.00	-3.61
0:30	4.93	0.00	0.12
0:40	10.03	0.00	0.00
0:50	16.64	0.00	0.00
1:00	23.92	0.01	0.00
1:10	31.16	0.01	0.00
1:20	37.87	0.02	0.00
1:30	43.86	0.00	0.00
1:40	49.21	0.00	0.00
1:50	53.80	0.00	0.00
2:00	57.32	0.00	0.00
2:10	60.59	0.00	0.00
2:20	63.01	0.00	0.00
2:30	63.03	0.00	0.00
2:41	62.83	0.00	0.00
2:51	62.84	0.00	0.00
3:01	62.85	0.00	0.00
3:11	64.05	0.00	0.00
3:21	65.01	0.00	0.00
3:31	66.03	0.00	0.00
3:41	67.05	0.00	0.00
3:51	68.06	0.00	0.00
4:01	69.06	-0.01	0.00
4:11	70.06	-0.01	0.00
4:21	71.05	-0.01	0.00
4:31	72.04	-0.01	0.00
4:41	73.01	-0.01	0.00

*Attitudes refer to Figure 1.

Table VII. Spacecraft Pitch, Yaw, and Roll Attitudes Along the Nominal Trajectory* (Continued)

Ground Elapsed Time from Lift-off (min:sec)	Pitch (deg)	Yaw (deg)	Roll (deg)
4:51	73.99	-0.01	0.00
5:01	74.95	-0.01	0.00
5:11	75.91	-0.01	0.00
5:21	76.87	-0.01	0.00
5:31	77.82	-0.01	0.00
5:41	78.76	-0.01	0.00
5:51	79.70	-0.01	0.00
6:01	80.63	-0.01	0.00
6:11	81.55	-0.01	0.00
6:21	82.47	-0.01	0.00
6:31	83.38	-0.01	0.00
6:41	84.28	-0.01	0.00
6:51	85.18	-0.01	0.00
7:01	86.06	-0.01	0.00
7:11	86.60	-0.03	0.00
7:21	87.51	-0.03	0.00
7:31	88.37	-0.02	0.00
7:41	89.22	-0.02	0.00
7:51	90.06	-0.02	0.00
8:01	90.89	-0.02	0.00
8:11	91.70	-0.01	0.00
8:21	92.50	-0.01	0.00
8:31	93.30	-0.01	0.00
8:41	94.10	-0.01	0.00
8:51	94.61	0.02	0.00
9:01	96.28	0.00	0.00
9:11	97.03	0.00	0.00
9:21	97.66	-0.01	0.00
9:31	98.27	-0.01	0.00

*Attitudes refer to Figure 1.

Table VII. Spacecraft Pitch, Yaw, and Roll Attitudes Along the Nominal Trajectory* (Continued)

Ground Elapsed Time from Lift-off (min:sec)	Pitch (deg)	Yaw (deg)	Roll (deg)
9:41	98.85	-0.01	0.00
9:51	99.40	-0.02	0.00
10:01	99.92	-0.02	0.00
10:11	100.42	-0.01	0.00
10:21	100.88	-0.01	0.00
10:31	101.32	-0.00	0.00
10:41	101.72	0.01	0.00
10:51	102.09	0.02	0.00
11:01	102.43	0.04	0.00
11:11	102.74	0.07	0.00
11:21	103.02	0.13	0.00
11:31	103.25	0.34	0.00
11:35.28 (INSERTION)	103.50	0.15	0.00

*Attitudes refer to Figure 1.

Table VIII. Full-lift Landing Range and Maximum Entry Load Factor Following Nominal Mode II Aborts

Ground Elapsed Time of Abort (min:sec)		Full-lift Landing Range (n mi)	Maximum Entry Load Factor (g)
3:06		435.57	9.766
3:11		459.27	9.989
3:31		513.23	10.811
3:51		568.08	12.038
4:11		592.18	12.103
4:31		646.23	12.726
4:51		703.90	13.262
5:11		765.70	13.756
5:31		832.52	14.225
5:51		905.63	14.531
6:11		986.65	14.728
6:31		1078.08	14.663
6:51		1183.70	14.546
7:11		1298.46	14.182
7:31		1421.42	13.588
7:51		1571.60	12.821
8:11		1765.83	11.726
8:31		2039.81	10.166
8:51		2309.03	8.814
9:11		2452.68	8.110
9:31		2619.26	7.333
9:51		2821.65	6.469
10:11	End of nominal	3077.57	5.518
10:31	Mode II	3426.11	4.519
10:51		3964.05	3.376
11:11		5032.72	2.888
11:26		7795.46	2.626
11:31		ORBITAL	ORBITAL

Table IX. Spacecraft Pitch Attitude* at Entry Interface Altitude (300,000 Feet) for Nominal Mode II Aborts

Ground Elapsed Time of Abort (min: sec)		Pitch Attitude (deg)
3:06		-42.56
3:11		-43.65
3:31		-40.99
3:51		-38.58
4:11		-40.01
4:31		-39.61
4:51		-39.31
5:11		-39.07
5:31		-38.86
5:51		-38.64
6:11		-38.37
6:31		-38.03
6:51		-37.55
7:11		-36.93
7:31		-36.16
7:51		-35.10
8:11		-33.54
8:31		-31.04
8:51		-28.31
9:11		-26.83
9:31		-25.13
9:51		-23.03
10:11	End of nominal	-20.32
10:31	Mode II	-16.51
10:51		-10.36
11:11		2.63
11:26		37.56
11:31		ORBITAL

*Pitch attitude refers to Figure 1.

Table X. Ground Elapsed Time from Lift-off to Entry Interface Altitude at 400,000 Feet and Drogue Chute Deployment at 23,500 Feet Following Nominal Mode II Aborts

Ground Elapsed Time of Abort (min: sec)		Ground Elapsed Time at 400,000 ft (min: sec)	Ground Elapsed Time at Drogue Chute Deployment (min: sec)
3:06		5:57.7	9:34.9
3:11		6:02.5	9:39.1
3:31		6:28.0	10:00.6
3:51		6:58.3	10:38.2
4:11		7:11.7	10:43.6
4:31		7:31.8	11:05.7
4:51		7:51.4	11:28.5
5:11		8:10.5	11:52.0
5:31		8:29.6	12:16.7
5:51		8:49.0	12:42.8
6:11		9:08.9	13:11.0
6:31		9:29.8	13:42.0
6:51		9:52.6	14:16.7
7:11		10:16.0	14:53.5
7:31		10:39.6	15:31.8
7:51		11:07.1	16:17.4
8:11		11:41.1	17:14.8
8:31		12:27.9	18:33.2
8:51		13:13.5	19:48.0
9:11		13:36.9	20:27.4
9:31		14:03.0	21:12.7
9:51		14:34.0	22:06.9
10:11	End of nominal	15:12.4	23:15.0
10:31	Mode II	16:04.3	24:46.8
10:51		17:24.5	27:06.6
11:11		20:06.0	31:42.3
11:26		25:40.7	42:20.2
11:31		ORBITAL	ORBITAL

Table XI. Ground Elapsed Time to Enter and Exit from VHF Communications Blackout Region Following Nominal Mode II Aborts

Ground Elapsed Time of Abort (min: sec)		Ground Elapsed Time (Enter Blackout Region) (min: sec)	Ground Elapsed Time (Exit Blackout Region) (min: sec)
3:06		-*	-*
3:11		-*	-*
3:31		-*	-*
3:51		-*	-*
4:11		8:27	8:32
4:31		8:41	8:53
4:51		8:57	9:12
5:11		9:13	9:32
5:31		9:30	9:52
5:51		9:46	10:12
6:11		10:04	10:34
6:31		10:24	10:58
6:51		10:45	11:24
7:11		11:07	11:52
7:31		11:30	12:21
7:51		11:57	12:56
8:11		12:32	13:40
8:31		13:21	14:43
8:51		14:10	15:45
9:11		14:35	16:19
9:31		15:04	16:58
9:51		15:39	17:46
10:11	End of nominal	16:23	18:48
10:31	Mode II	17:23	20:16
10:51		18:58	22:42
11:11		22:13	27:45
11:26		-**	38:20
11:31		ORBITAL	ORBITAL

*VHF communications blackout does not occur during entry.

**VHF communications blackout occurs prior to reaching the entry interface.

Table XII. Spacecraft Pitch Attitude, Inertial and Relative Flight-path Angles, and Inertial Velocity at 400,000-Foot Entry Altitude Following Nominal Mode II Aborts

Ground Elapsed Time of Abort (min: sec)		Pitch Attitude at Entry (deg)*	Inertial Flight-path Angle at Entry (deg)	Relative Flight-path Angle at Entry (deg)	Inertial Velocity at Entry (ft/sec)
3:06		-50.17	-11.76	-13.72	9,127.51
3:11		-49.70	-12.08	-14.06	9,224.59
3:31		-46.82	-13.37	-15.41	9,795.40
3:51		-45.61	-15.70	-17.96	10,369.73
4:11		-44.97	-14.27	-16.18	10,961.38
4:31		-44.15	-14.22	-16.01	11,574.99
4:51		-43.52	-13.96	-15.62	12,215.14
5:11		-43.02	-13.53	-15.05	12,886.56
5:31		-42.59	-12.98	-14.35	13,594.38
5:51		-42.19	-12.32	-13.55	14,344.26
6:11		-41.79	-11.59	-12.67	15,142.58
6:31		-41.34	-10.78	-11.74	15,996.74
6:51		-40.79	-9.92	-10.74	16,915.42
7:11		-40.12	-9.08	-9.79	17,824.63
7:31		-39.35	-8.28	-8.90	18,698.82
7:51		-38.33	-7.43	-7.96	19,639.28
8:11		-36.88	-6.52	-6.97	20,656.32
8:31		-34.58	-5.55	-5.91	21,762.76
8:51		-32.08	-4.84	-5.14	22,563.93
9:11		-30.76	-4.50	-4.77	22,924.03
9:31		-29.27	-4.14	-4.39	23,294.41
9:51		-27.45	-3.75	-3.97	23,675.37
10:11	End of nominal	-25.14	-3.32	-3.51	24,067.40
10:31	Mode II	-21.93	-2.85	-3.01	24,470.97
10:51		-16.82	-2.30	-2.43	24,886.46
11:11		-6.24	-1.61	-1.70	25,313.60
11:26		20.73	-0.84	-0.88	25,638.32
11:31		ORBITAL	ORBITAL	ORBITAL	ORBITAL

*Attitudes refer to Figure 1.

Table XIII. Maximum Entry Load Factor and Time of Free Fall to Entry Interface Altitude Following Nominal Mode III Aborts

Ground Elapsed Time of Abort (min:sec)	Maximum Entry Load Factor (g)	Time of Free Fall to 300,000-Foot Entry Altitude (min:sec)
10:36	6.60	04:14.4
10:46	6.75	03:42.9
10:56	7.05	03:10.6
11:06	8.15	02:13.7
11:16	8.24	02:06.8
11:21	8.95	01:44.3
11:26	9.64	01:26.2

Table XIV. Ground Elapsed Time from Lift-off to Enter and Exit from the VHF Communications Blackout Region Following Nominal Mode III Aborts

Ground Elapsed Time of Abort (min:sec)	Ground Elapsed Time (Enter Blackout Region) (min:sec)	Ground Elapsed Time (Exit Blackout Region) (min:sec)
10:36	17:15	19:39
10:46	17:13	19:36
10:56	17:12	19:34
11:06	17:10	19:33
11:16	17:09	19:32
11:21	17:08	19:29
11:26	17:07	19:28

Table XV. Discrete Times at 400,000-Foot Entry Interface Altitude, 0.2 g, and Drogue Chute Deployment and Spacecraft Orientation and Inertial Velocity at 400,000 Feet Following Nominal Mode III Aborts

Ground Elapsed Time of Abort (min:sec)	Ground Elapsed Time at 400,000 ft (min:sec)	Ground Elapsed Time Drogue Chute Deployment (min:sec)	Ground Elapsed Time at 0.2 g (min:sec)	Pitch Attitude at Entry (deg)*	Inertial Flight-path Angle (deg)	Relative Flight-path Angle (deg)	Inertial Velocity (ft/sec)
10:36	15:58:4	22:47.0	17:39.90	-22.18	-2.956	-3.122	24,468
10:46	16:01.3	22:44.9	17:39.47	-21.77	-3.083	-3.257	24,515
10:56	16:07.3	22:40.0	17:40.41	-21.07	-3.283	-3.467	24,548
11:06	16:08.8	22:17.8	17:30.13	-19.05	-3.848	-4.065	24,477
11:16	16:31.0	22:37.8	17:50.46	-18.61	-3.947	-4.169	24,570
11:21	16:38.4	22:31.8	17:52.17	-17.72	-4.290	-4.531	24,537
11:26	16:28.3	22:10.3	17:37.36	-16.73	-4.618	-4.878	24,517

*Attitudes refer to Figure 1.

Table XVI. Spacecraft Pitch Attitude at SPS Ignition and at Entry Interface Altitude (300, 000 Feet) Following Nominal Mode III Aborts

Ground Elapsed Time of Abort (min:sec)	Pitch Attitude* at SPS Ignition (deg)	Pitch Attitude* at Entry (deg)
10:36	255.01	-16.9
10:46	255.69	-16.7
10:56	256.38	-16.3
11:06	256.38	-14.9
11:16	257.70	-14.6
11:21	258.02	-14.0
11:26	258.28	-13.2

*Attitudes refer to Figure 1.

Table XVII. SPS ΔV Expended and SPS Burn Time Following Nominal Mode III Aborts

Ground Elapsed Time of Abort (min:sec)	ΔV Necessary to Achieve Half-lift Landing Range = 3200 n mi (ft/sec)	SPS Burn Time (min:sec)
10:36	152.84	00:13.93
10:46	398.22	00:35.85
10:56	679.47	01:11.18
11:06	1155.45	01:40.26
11:16	1377.00	01:58.22
11:21	1641.22	02:19.12
11:26	1896.45	02:38.80

Table XVIII. Fixed ΔV Mode Nominal Launch Abort Data

Ground Elapsed Time of Abort (min:sec)	Inertial Velocity (ft/sec)	Altitude Rate* (ft/sec)	Delay Time (min:sec)	Pitch Attitude at SPS Ignition** (deg)	Pitch Attitude At Entry** (300K)(deg)	Time of Free Fall (min:sec)
11:30.00	25,453.89	-25.94	25:30.70	-2.21	71.57	1:19.08
11:31.00	25,476.56	-21.34	24:04.86	-9.06	72.29	2:54.88
11:32.00	25,505.42	-15.53	22:44.39	-15.35	72.72	4:42.35
11:34.00	25,544.95	-6.40	20:15.24	-26.62	72.99	6:58.50
11:35.28	25,574.13	0.00	18:42.50	-33.38	72.79	8:31.02
28:22.30	25,577.20	0.00	2:05.00	-32.67	62.78	8:21.00

*Minus sign indicates that the inertial flight-path angle is negative

**Pitch attitudes refer to Figure 1

Note: The ΔV used was 600 feet per second and the landing range was 8800 nautical miles.

Table XIX. Ground Elapsed Time from Lift-off to Enter and Exit from the VHF Communications Blackout Region Following Nominal Fixed ΔV Aborts

Ground Elapsed Time of Abort (min:sec)	Ground Elapsed Time (Enter Blackout Region) (min:sec)	Ground Elapsed Time (Exit Blackout Region) (min:sec)
11:30.00	38:56	43:37
11:31.00	39:07	43:39
11:32.00	39:15	43:41
11:34.00	39:21	43:45
11:35.28	39:19	43:46
28:22.30	39:19	43:46

Table XX. Discrete Times at 400,000-Foot Entry Interface Altitude, 0.2 g, and Drogue Chute Deployment and Spacecraft Orientation and Inertial Velocity at 400,000 Feet Following Nominal Fixed ΔV Aborts

Ground Elapsed Time of Abort (min:sec)	Ground Elapsed Time at 400,000 ft (min:sec)	Ground Elapsed Time at Drogue Chute Deployment (min:sec)	Pitch Attitude at Entry* (deg)	Inertial Flight-path Angle (deg)	Relative Flight-path Angle (deg)	Inertial Velocity (ft/sec)
11:31.00	36:40.0	46:46.2	62.62	-1.433	-1.510	25,329.8
11:32.00	36:56.1	46:48.5	63.08	-1.786	-1.880	25,482.3
11:34.00	37:09.5	46:52.4	63.54	-1.656	-1.744	25,412.3
11:35.28	37:09.1	46:53.8	63.70	-1.671	-1.760	25,444.9
28:22.30	37:08.5	46:53.5	63.67	-1.665	-1.755	25,440.6

*Attitude refers to Figure 1.

Table XXI. SPS Burn Time and SPS ΔV Increase Necessary to Increase Perigee Altitude to 75 Nautical Miles for Nominal Mode IV Procedure

Ground Elapsed Time of Abort (min:sec)	ΔV Necessary to Increase Perigee Altitude to 75 n mi (ft/sec)	SPS Burn Time (min:sec)
10:06	2225.3	3:03.9
10:11	2072.7	2:52.1
10:21	1791.2	2:30.7
10:41	1266.4	1:39.3
10:51	1012.9	1:28.5
11:01	762.4	1:07.4
11:11	515.3	0:46.1
11:21	270.9	0:24.5
11:31	29.3	0:02.7

Table XXII. Pitch Angle* at SPS Ignition for Nominal Mode IV Procedure

Ground Elapsed Time of Abort (min:sec)	Pitch Attitude at SPS Ignition (deg)
10:06	99.6
10:11	100.0
10:21	100.7
10:41	102.2
10:51	103.0
11:01	103.8
11:11	104.9
11:21	105.4
11:31	106.2

*Pitch attitude refers to Figure 1.

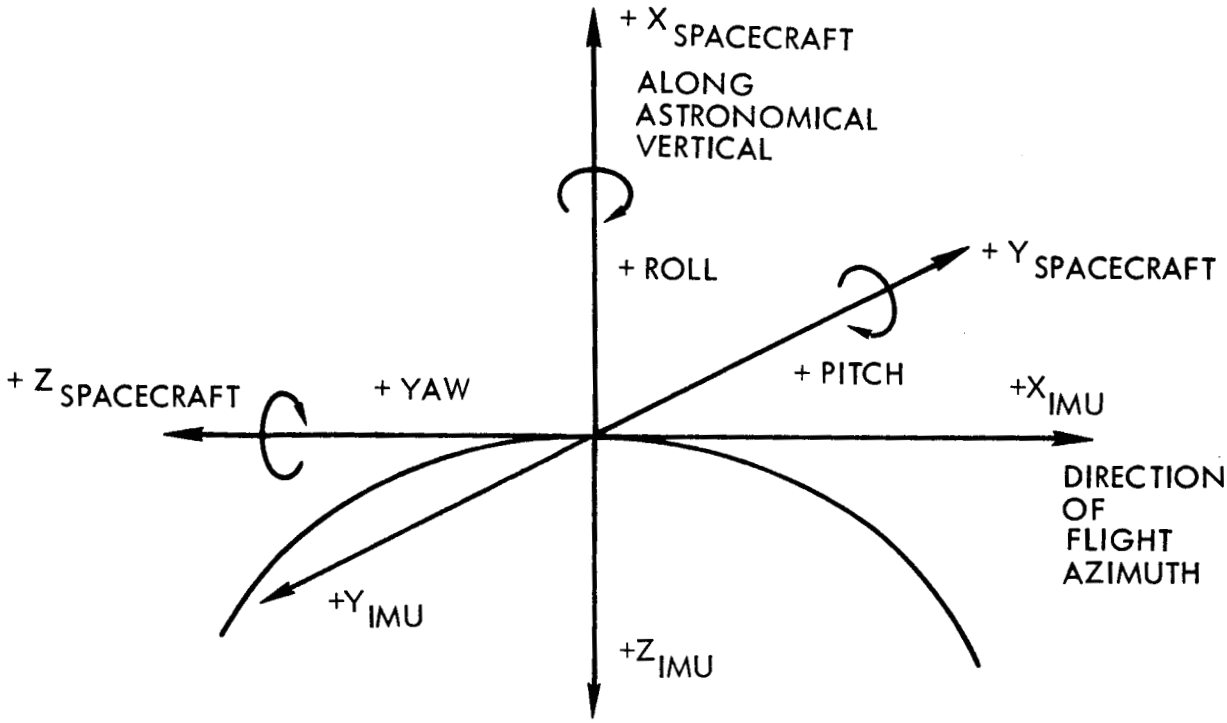


Figure 1. Launch Site Inertial Coordinate System Used to Define Spacecraft Attitudes

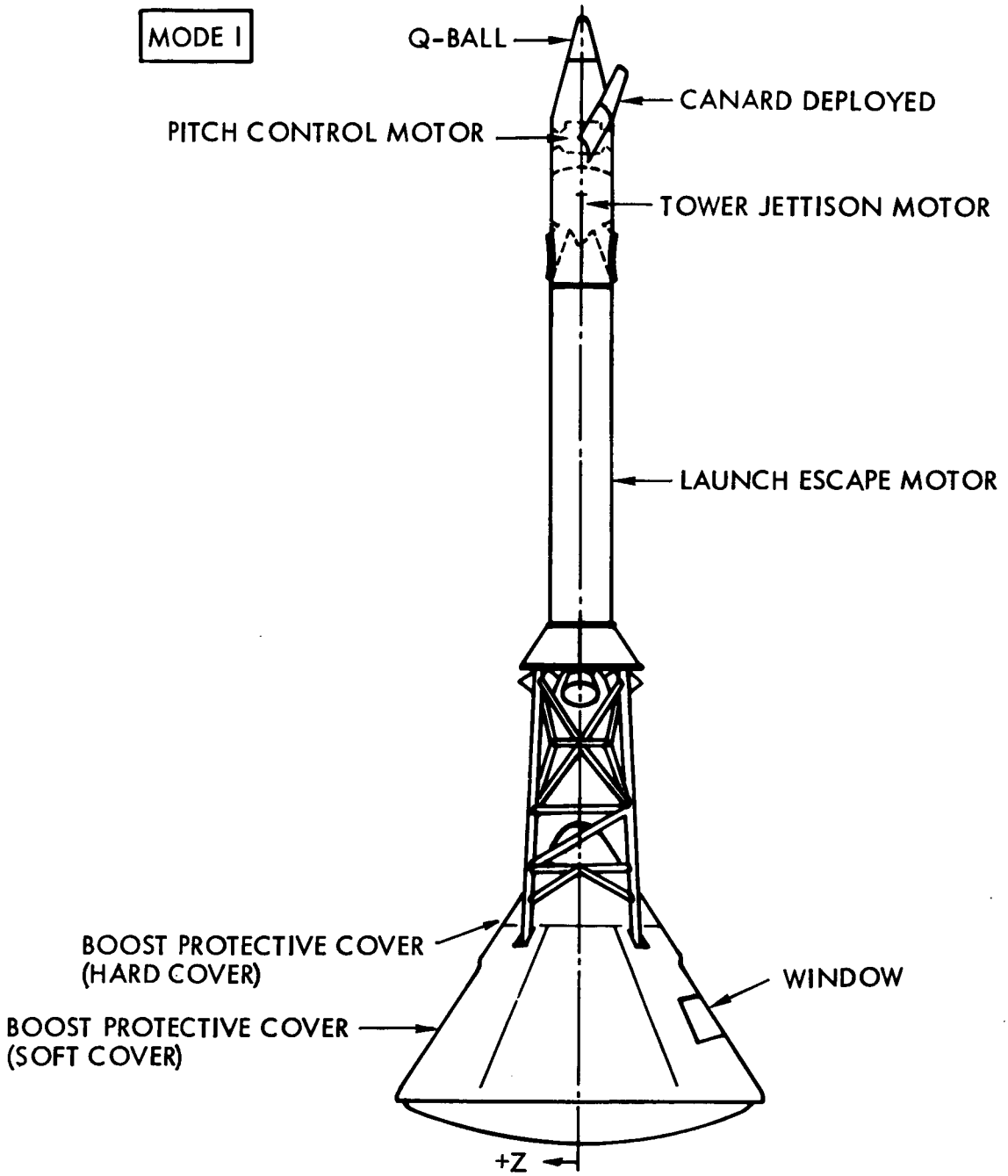
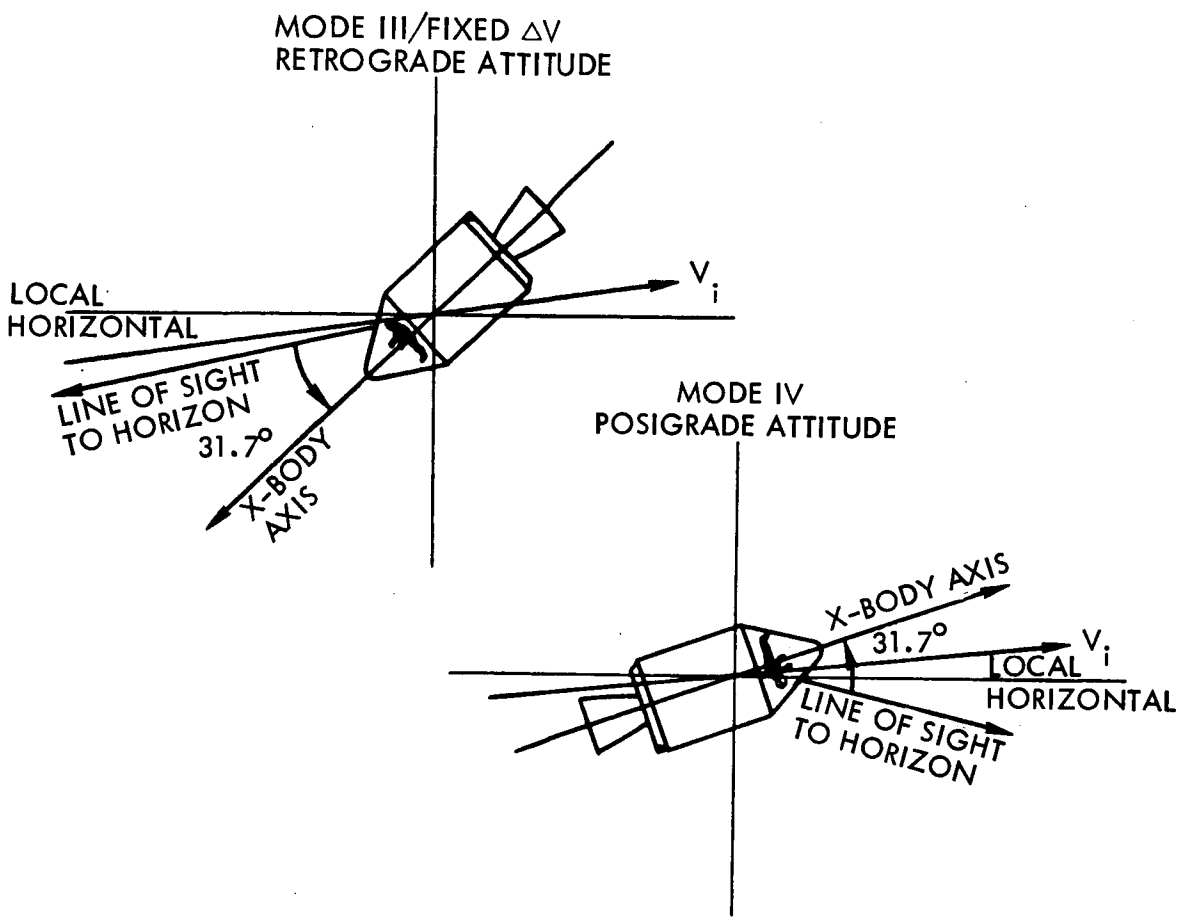


Figure 2. Launch Escape Vehicle Configuration



NOTE: SPS RETROGRADE AND POSIGRADE MANEUVERS WILL NORMALLY BE INITIATED AT BOOSTER CUTOFF PLUS 125 SECONDS FOR ALL LAUNCH ABORTS REQUIRING SPS MANEUVERS. THE ATTITUDES PRESENTED ABOVE ARE THE REQUIRED SPACECRAFT ORIENTATIONS AT SPS IGNITION. THE SUBSEQUENT ABORT MANEUVER WILL BE CONTROLLED VIA THE SCS; WHEREBY, THE SCS SHALL MAINTAIN THE INERTIAL ATTITUDE WHICH CORRESPONDS TO THE RELATIVE ATTITUDE AT SPS IGNITION.

Figure 3. CSM Orientations for RCS Ullage and SPS Ignition Prior to Performing Mode III, Fixed ΔV, or Mode IV Aborts

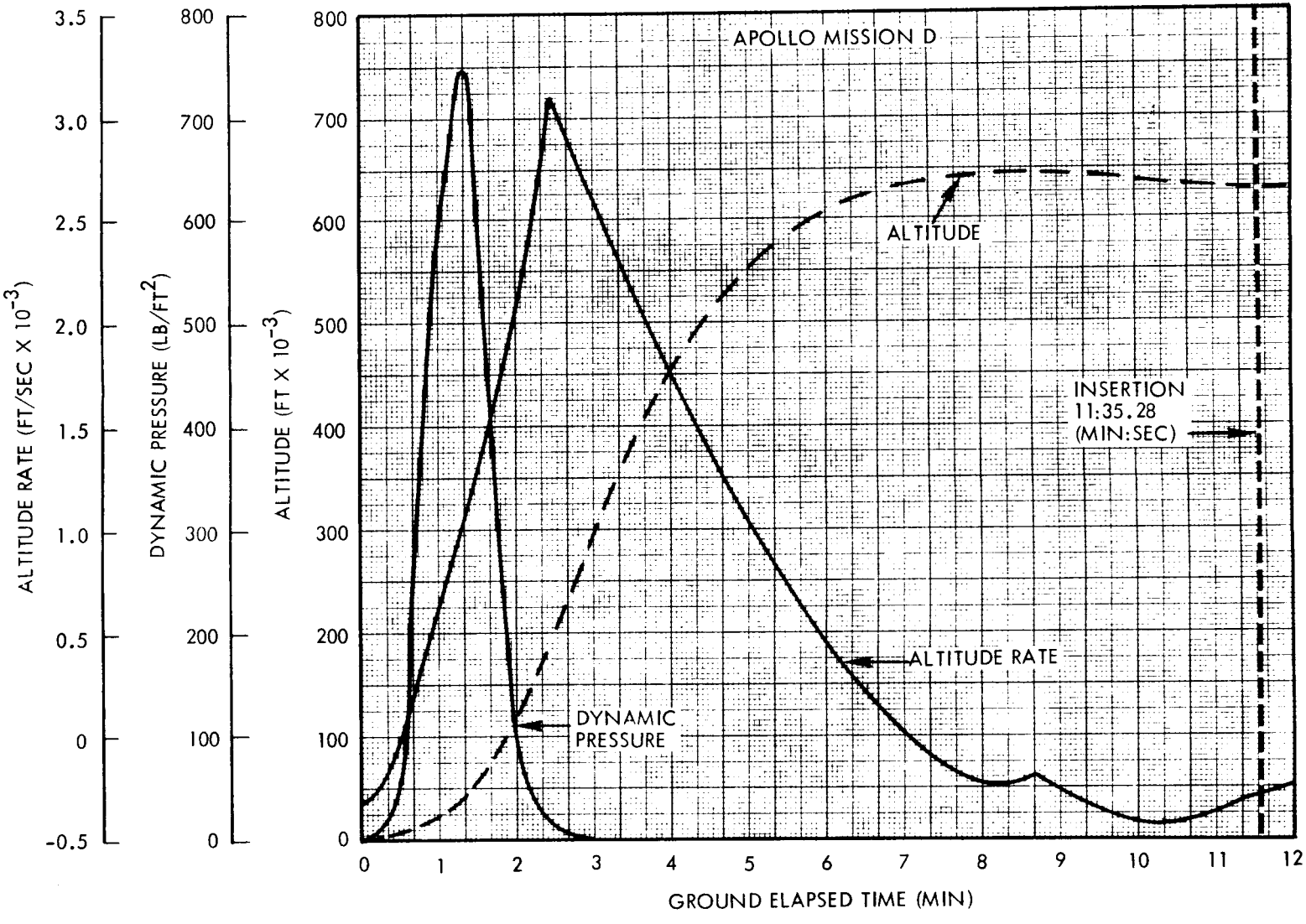
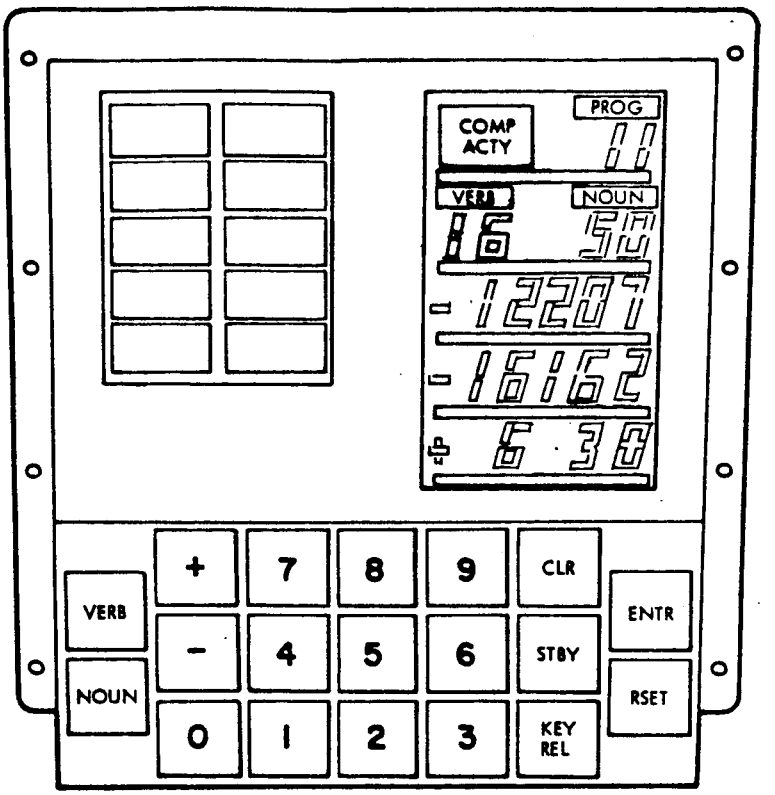


Figure 4. Nominal Altitude Rate, Altitude, and Dynamic Pressure from the Apollo Mission D Nominal Launch Trajectory



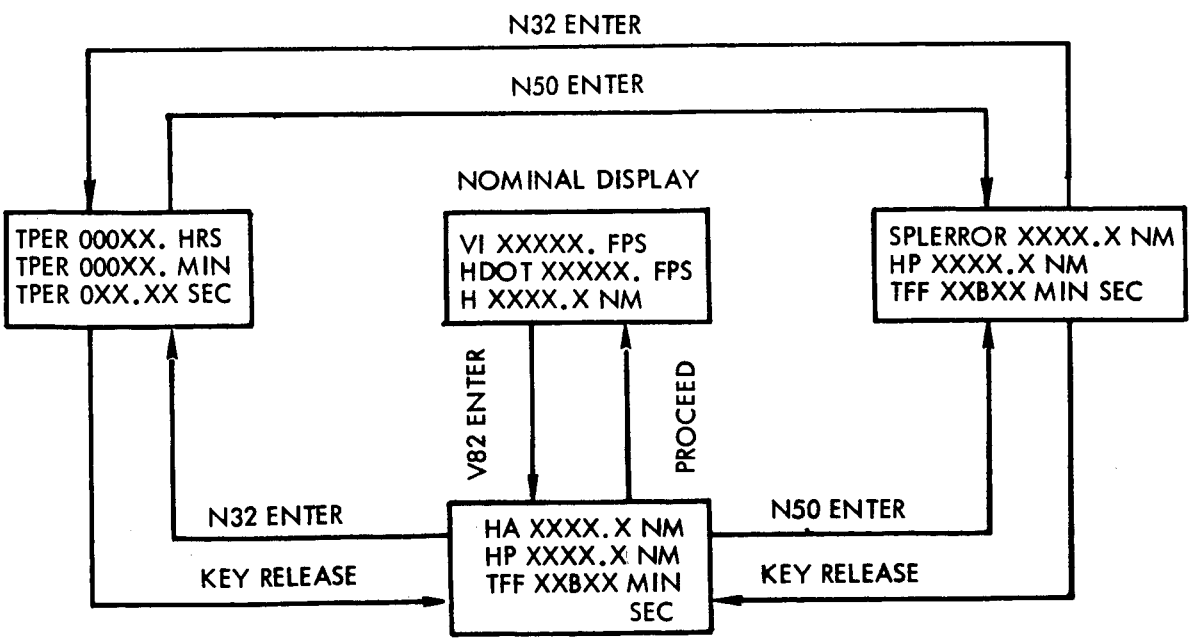


Figure 5. COLOSSUS Program 11 DSKY Pattern

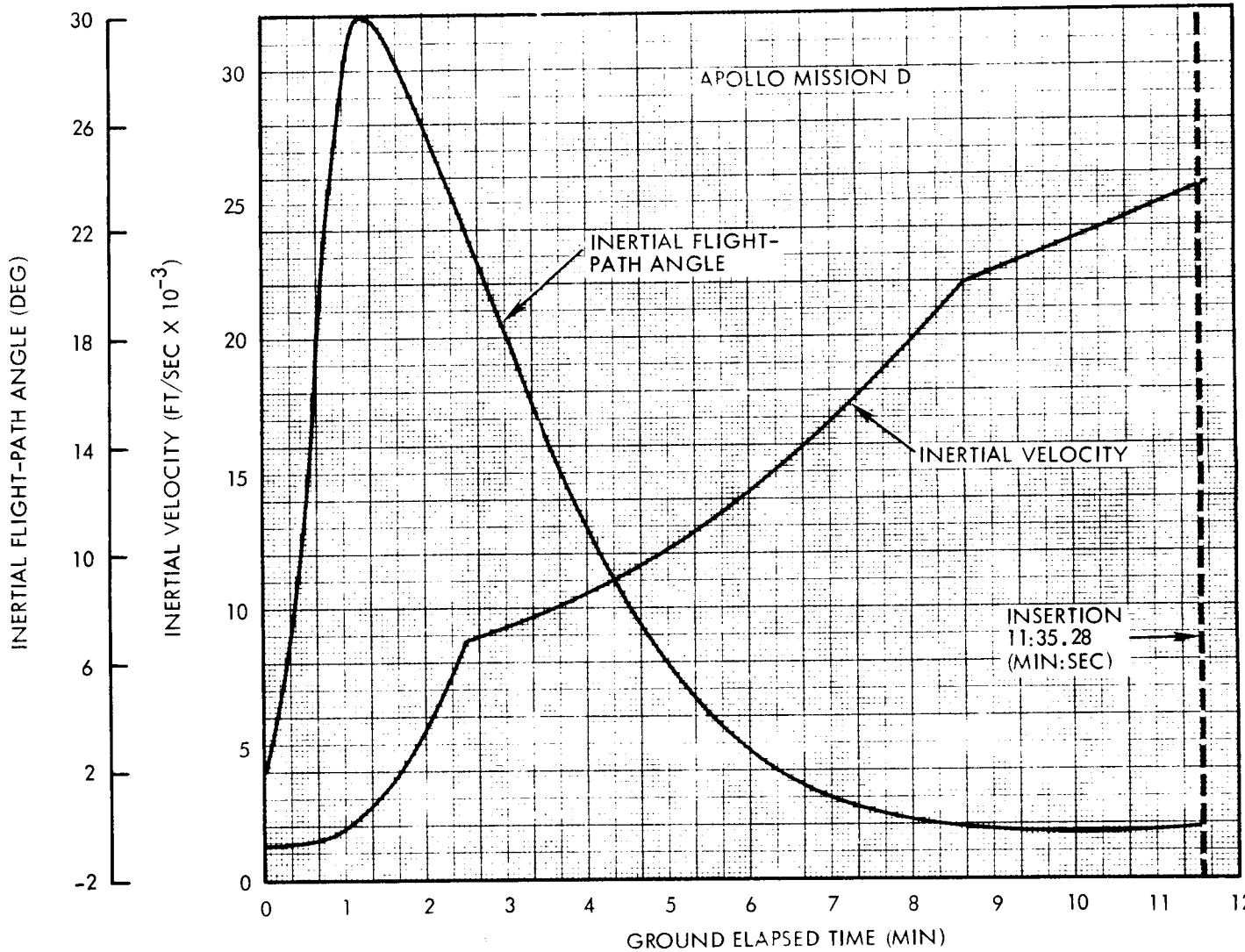


Figure 6. Nominal Inertial Flight-path Angle and Inertial Velocity for the AS-503 Launch Trajectory

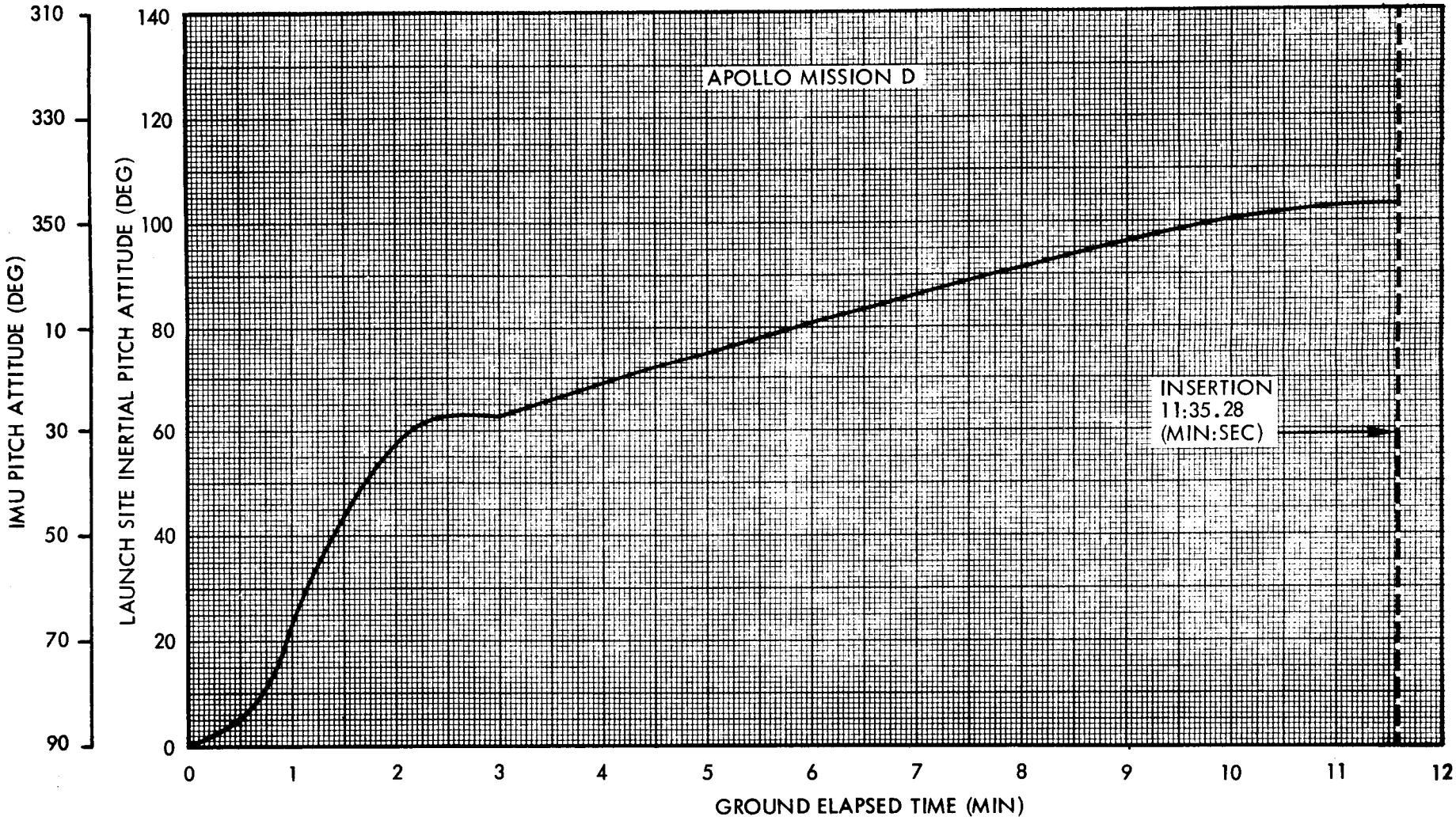


Figure 7. Spacecraft Pitch Attitude on the Nominal Launch Trajectory versus Ground Elapsed Time

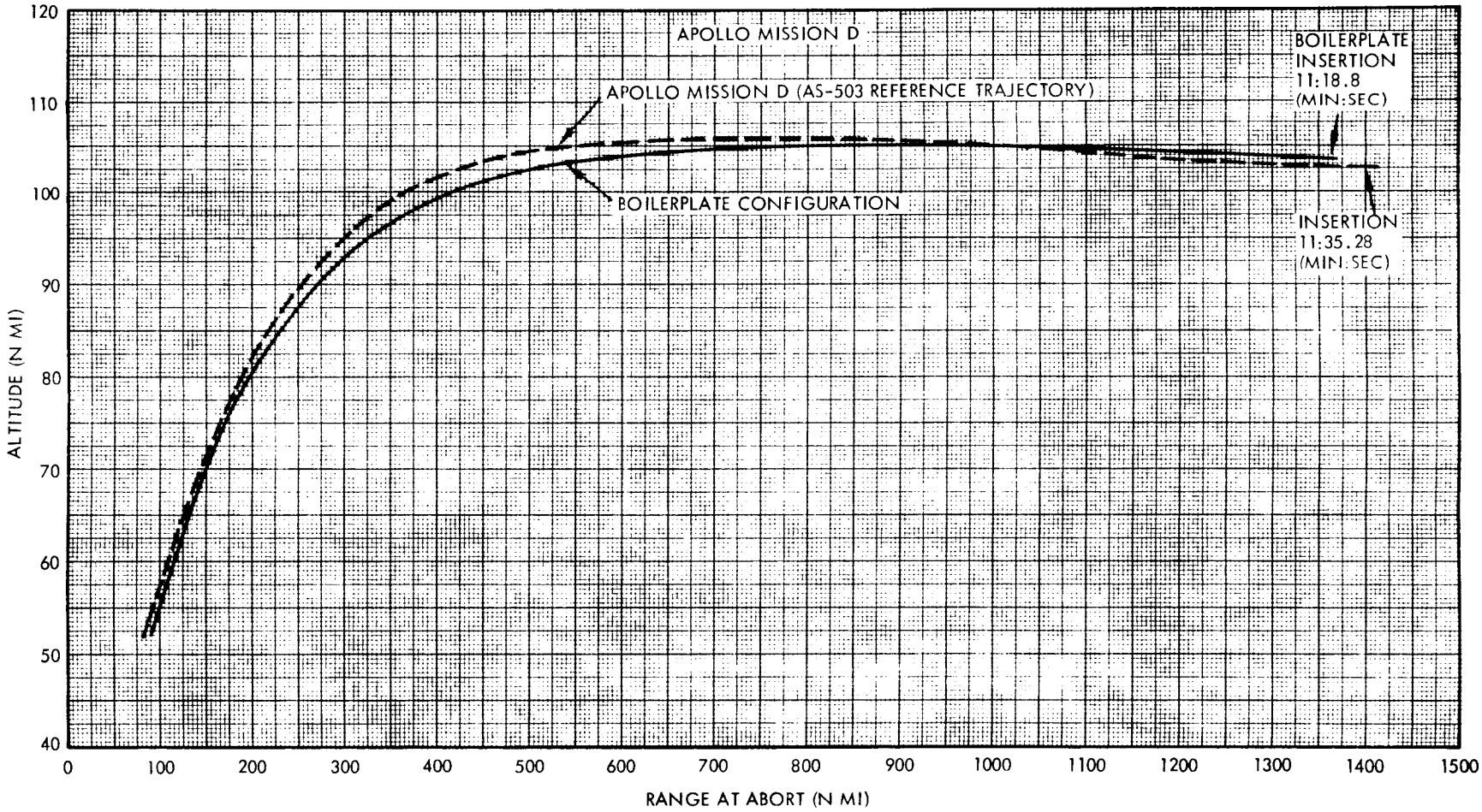


Figure 8. Nominal Launch Trajectory Altitude versus Range for Both Reference 4 (AS-503 Reference Trajectory) and Reference 5 (Boilerplate Configuration)

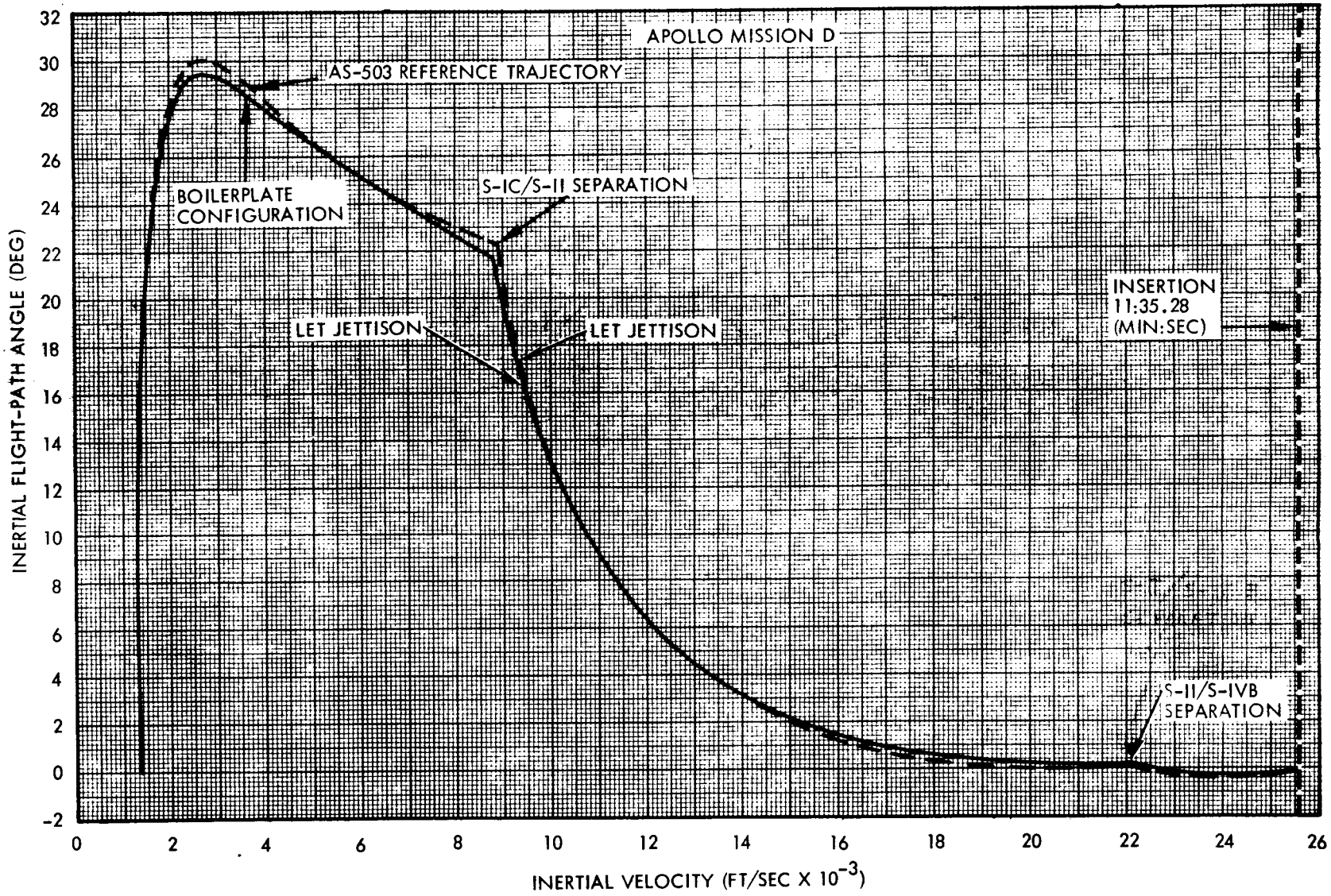


Figure 9. Inertial Flight-path Angle versus Inertial Velocity for the Entire Nominal Profiles of Both Reference 4 (AS-503 Reference Trajectory) and Reference 5 (Boilerplate Configuration)

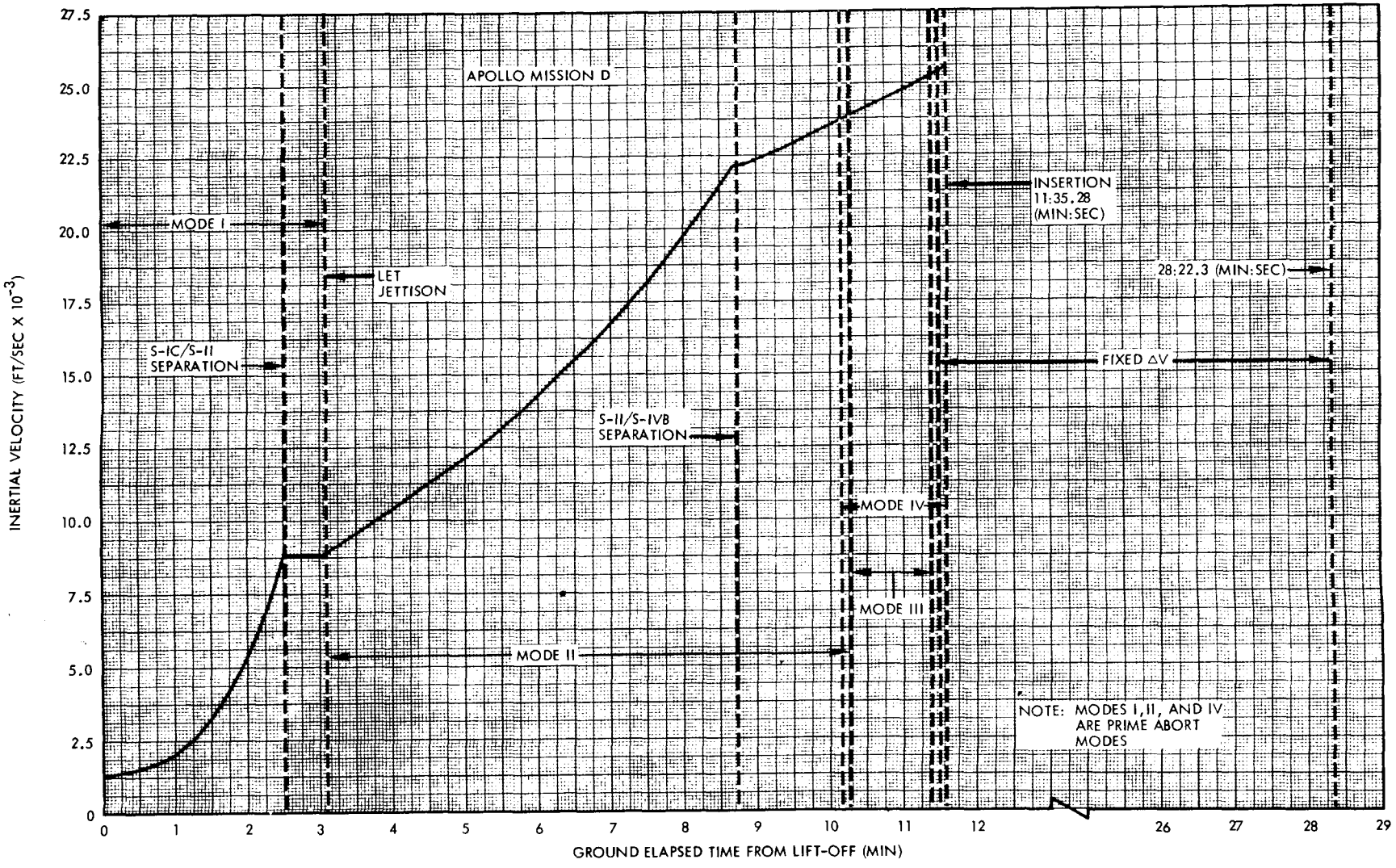


Figure 10. Nominal Launch Abort Regions as Partitions on the Nominal Inertial Velocity versus Ground Elapsed Timeline

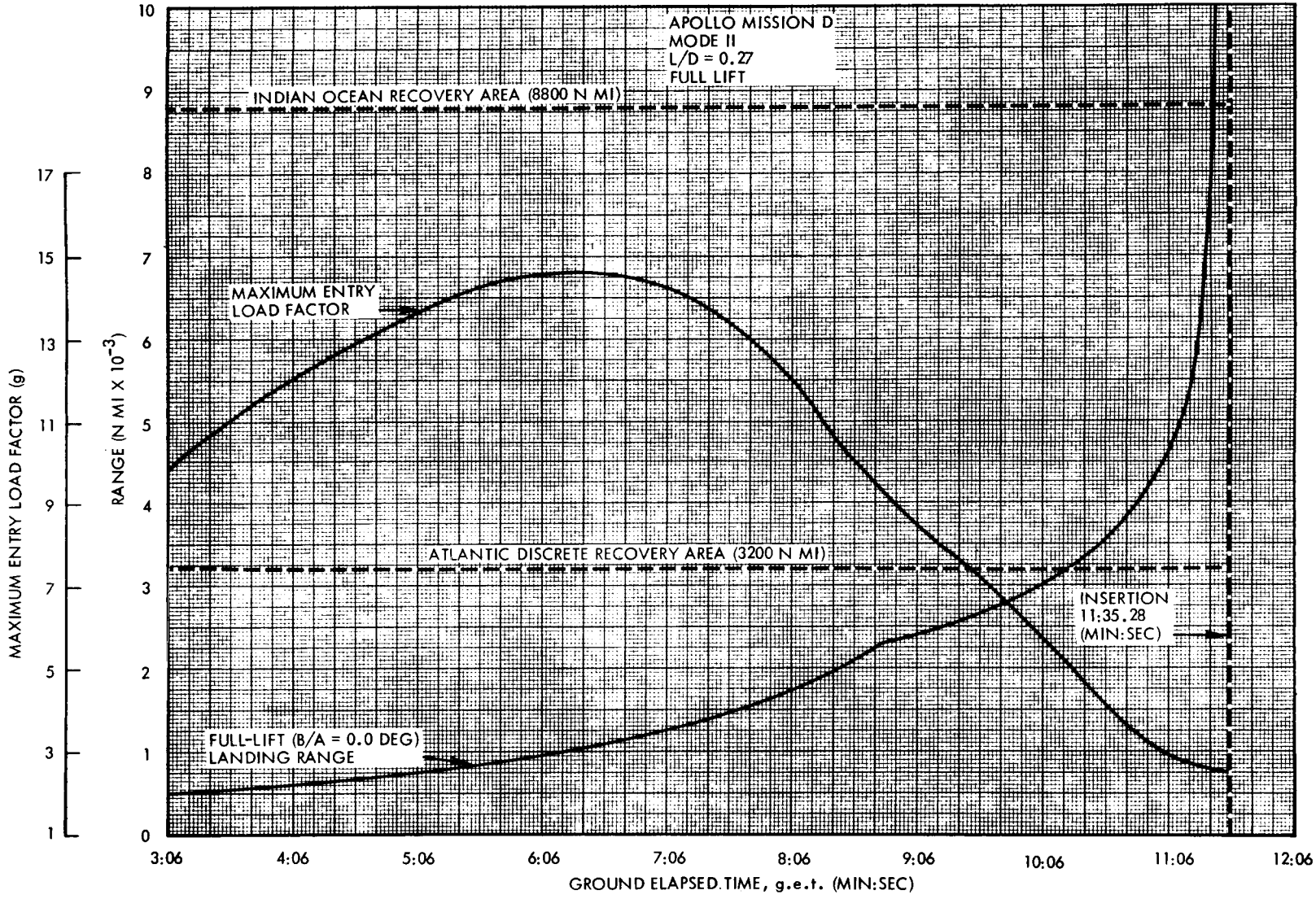


Figure 11. Full-lift Landing Range and Maximum Entry Load Factor versus Ground Elapsed Time for Mode II Aborts

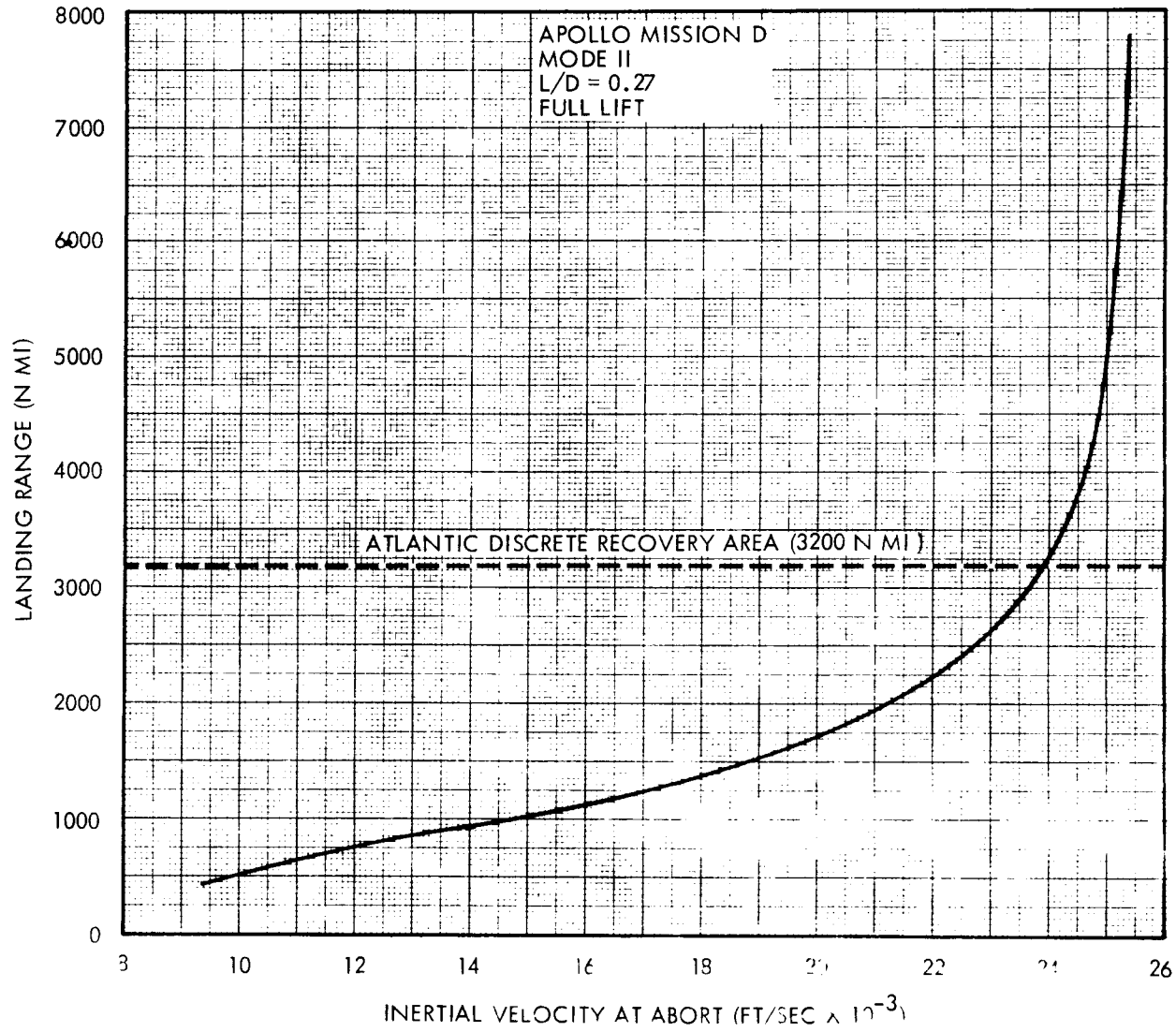


Figure 12. Landing Range versus Inertial Velocity for Mode II Full-lift Entries

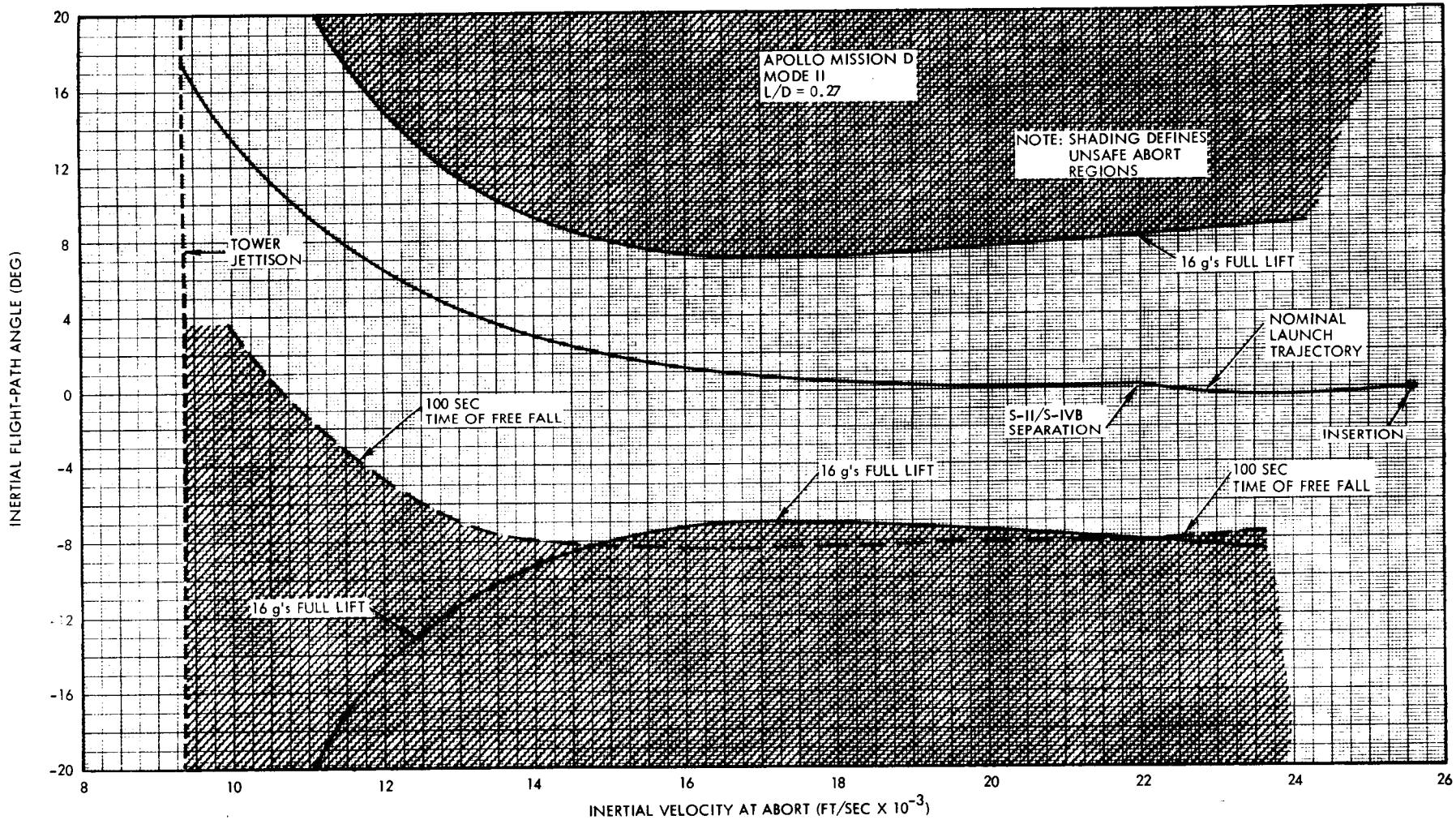


Figure 13. The Maximum Entry Load Factor Limit Lines (16 g's) and the Minimum Sequence Limit Line (100 Seconds Time of Free Fall) for Mode II Aborts (Full-lift Entry)

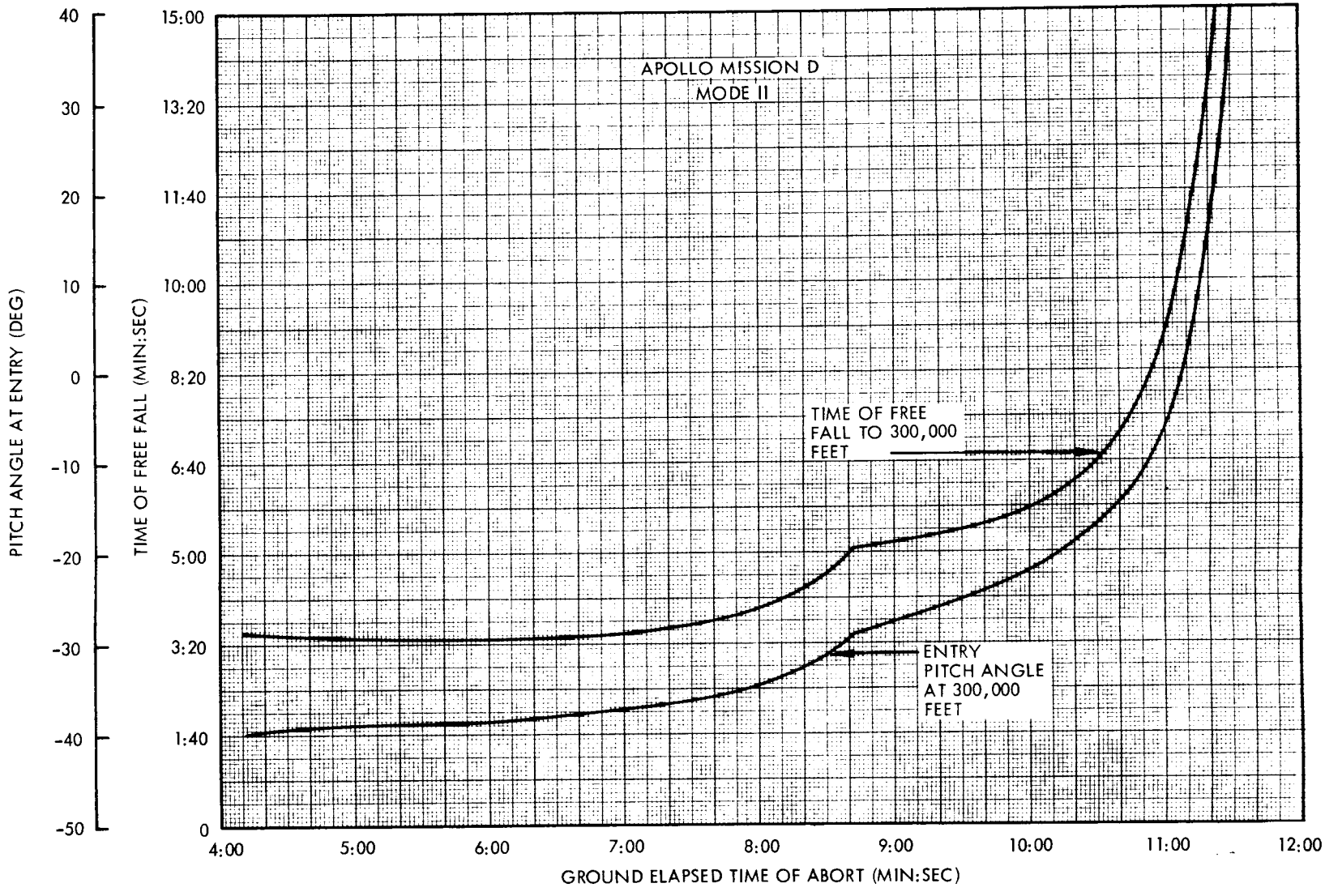


Figure 14. Time of Free Fall to 300,000 Feet and Pitch Angle at 300,000 Feet versus Ground Elapsed Time for Nominal Mode II Aborts

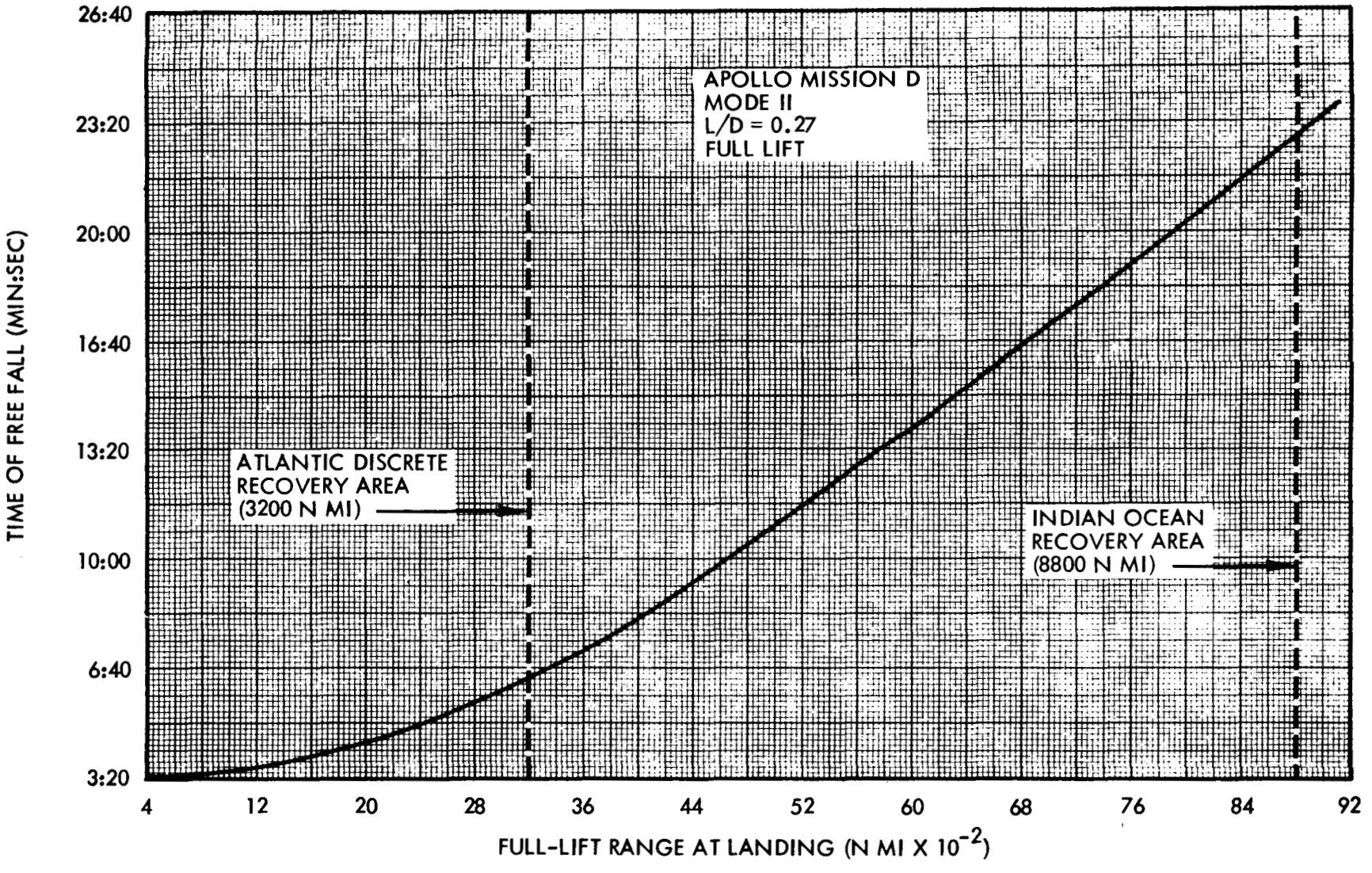


Figure 15. Time of Free Fall versus Full-lift Range at Landing for Mode II Aborts

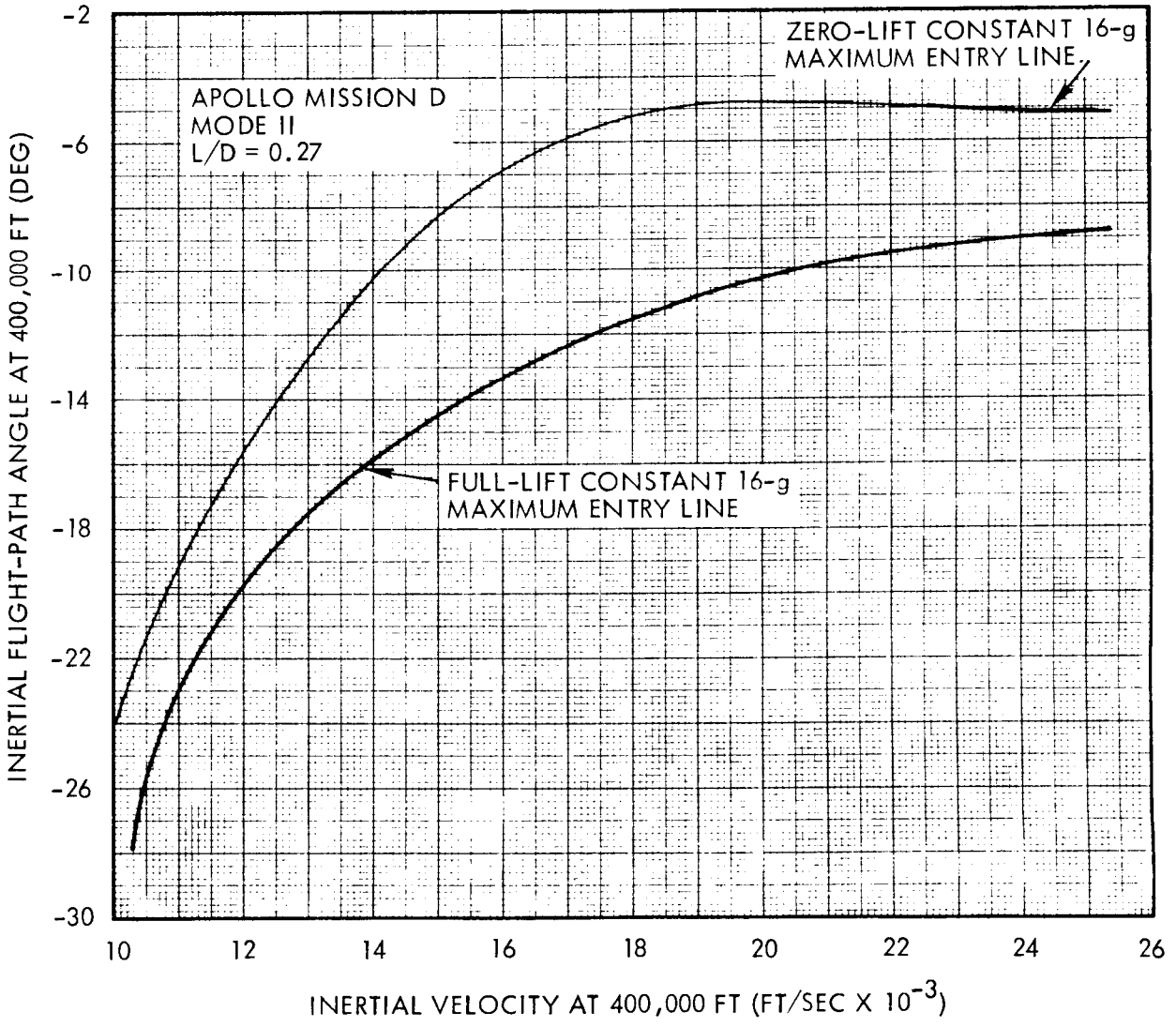


Figure 16. Inertial Velocity and Inertial Flight-path Angle at an Entry Interface of 400, 000 Feet for Zero-lift 16-g Maximum Entry Load Factor and Full-lift 16-g Maximum Entry Load Factor for Mode II Aborts

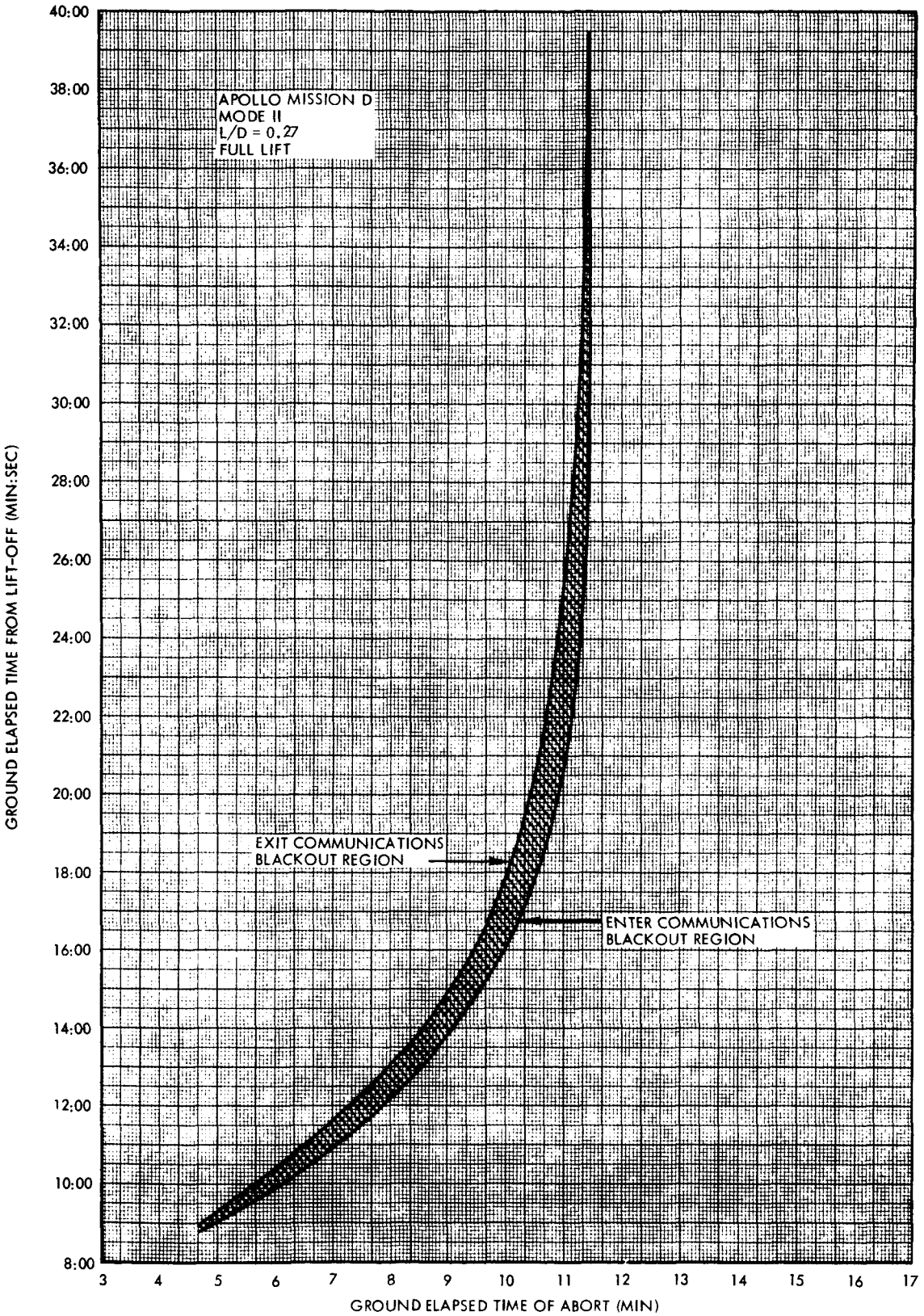


Figure 17. Ground Elapsed Time from Lift-off at the Entry and Exit from the VHF Communications Blackout Region versus Ground Elapsed Time of Abort for Mode II Aborts

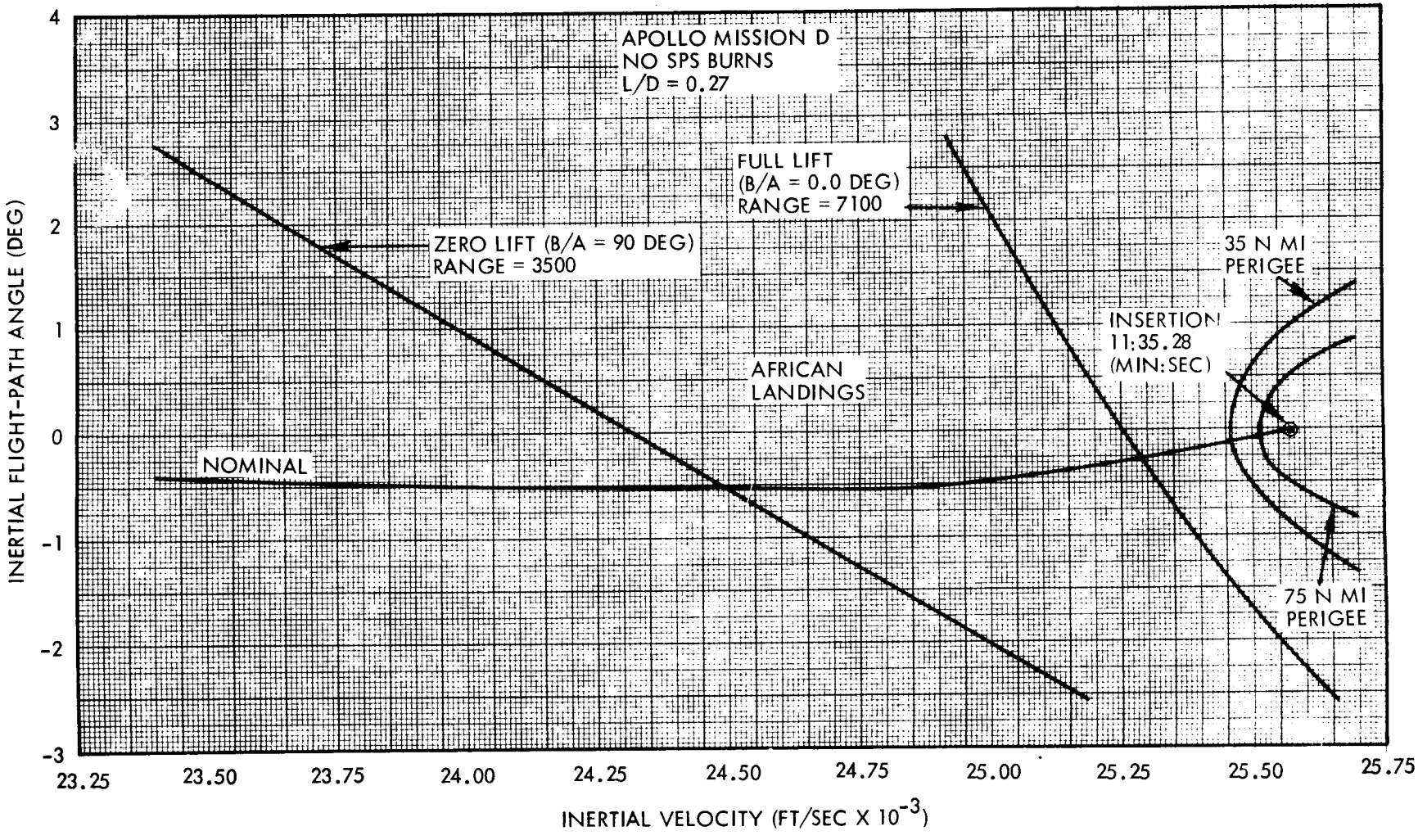


Figure 18. Zero Lift to the West Coast of Africa, Full Lift to the East Coast of Africa, 35-Nautical Mile Perigee and 75-Nautical Mile Perigee for Mode II (no SPS Burn) Aborts

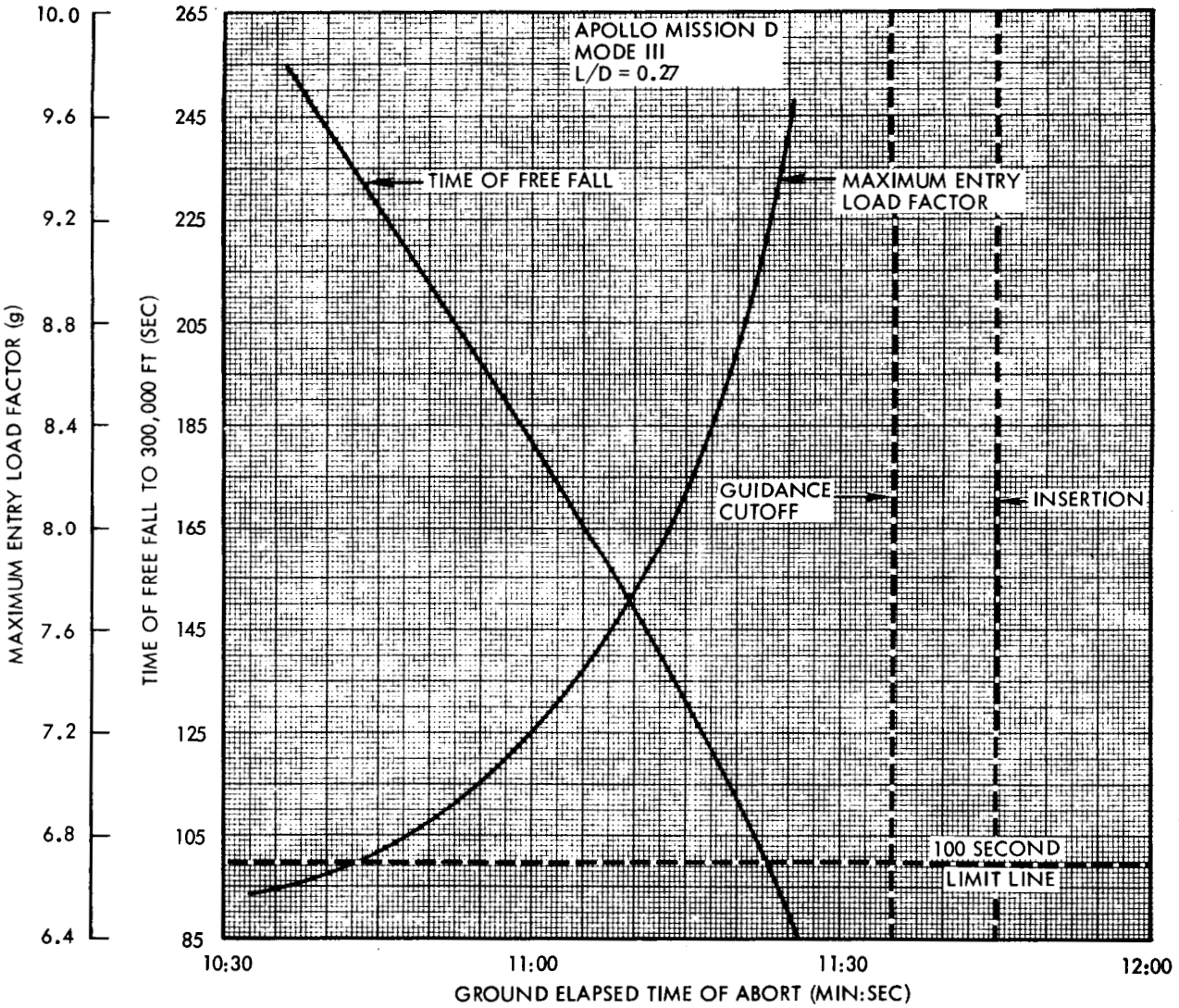


Figure 19. Maximum Entry Load Factor and Time of Free Fall for Nominal Mode III Aborts

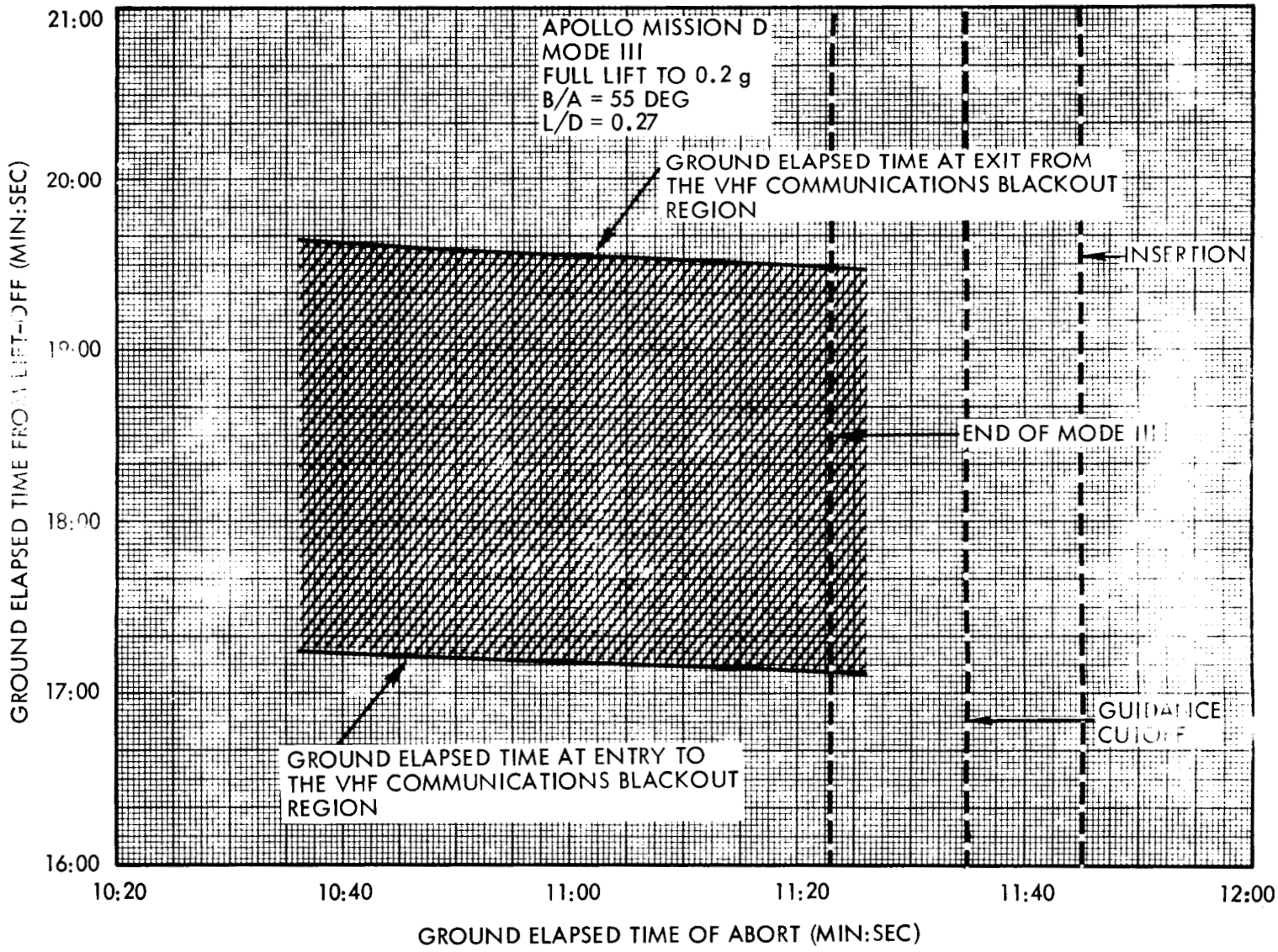


Figure 20. Ground Elapsed Time at Entry and Exit from the VHF Communications Blackout Region for Mode III Aborts

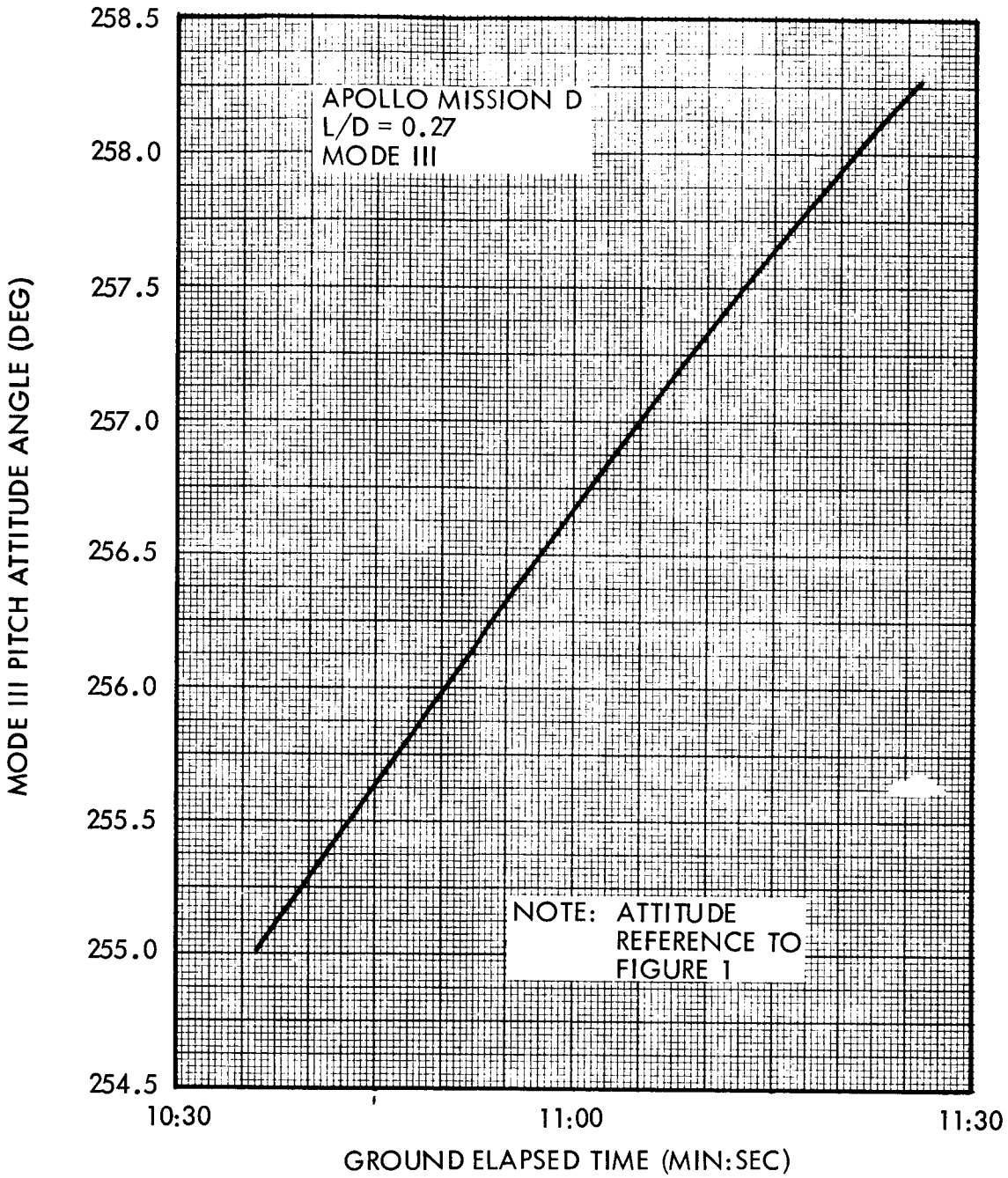


Figure 21. Spacecraft Pitch Attitude at SPS Ignition at Ground Elapsed Time of Abort for Mode III Aborts

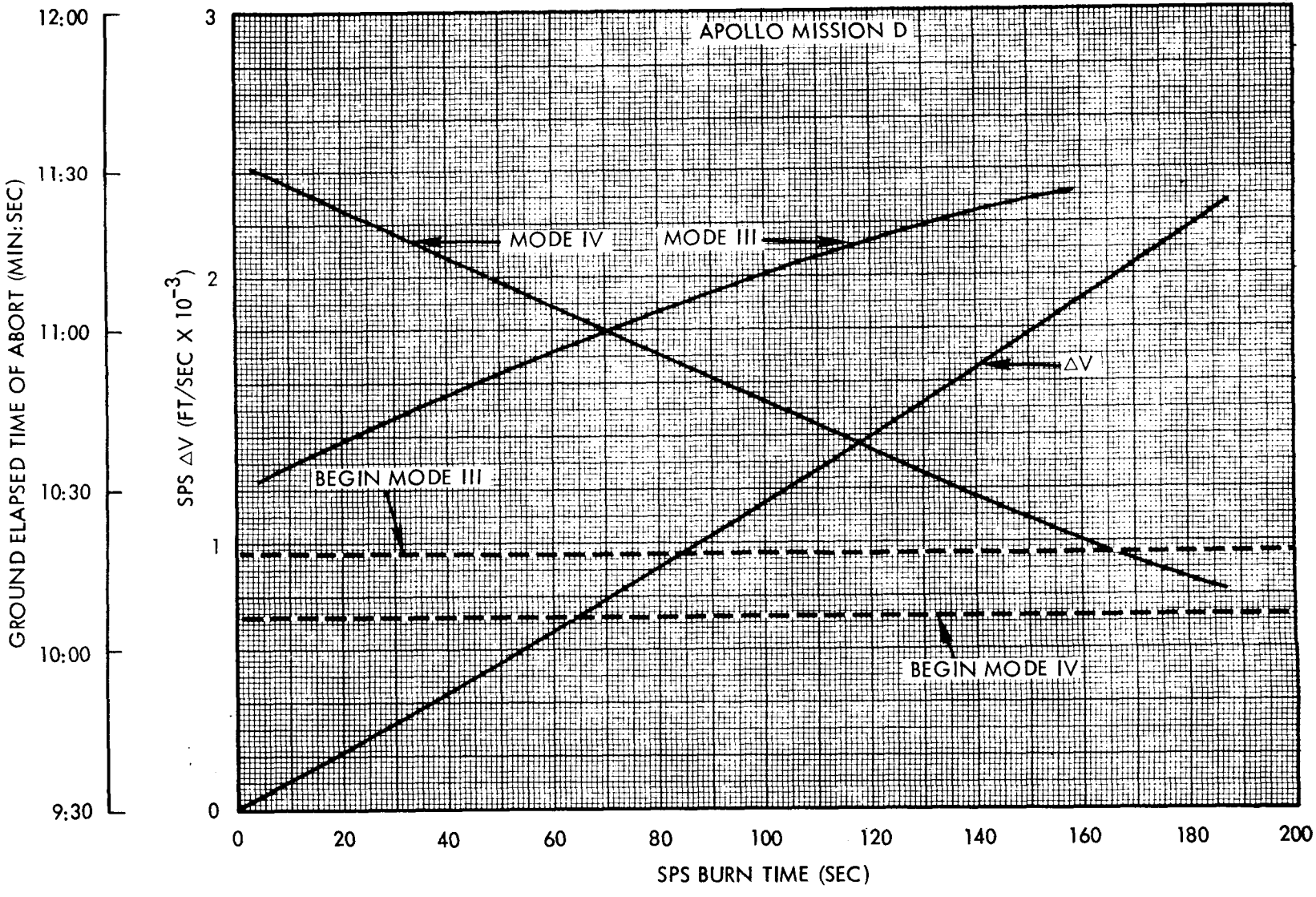


Figure 22. Ground Elapsed Time of Abort and SPS ΔV Expended versus SPS Burn Time for Mode III and Mode IV Aborts

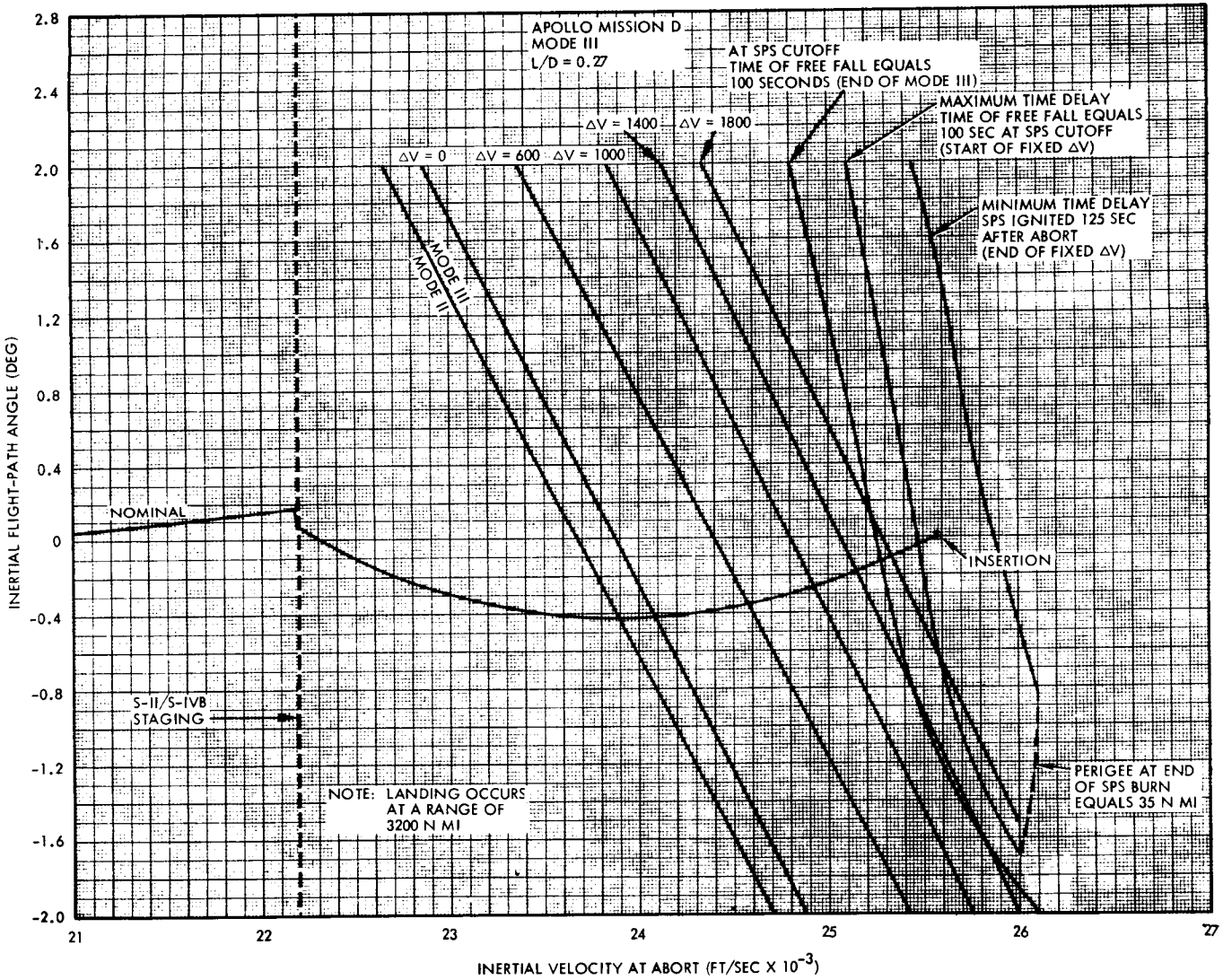


Figure 23. Mode III Regime Showing Constant SPS ΔV Lines, the Time-of-free-fall Limit Line for Mode III, and the Fixed ΔV Region

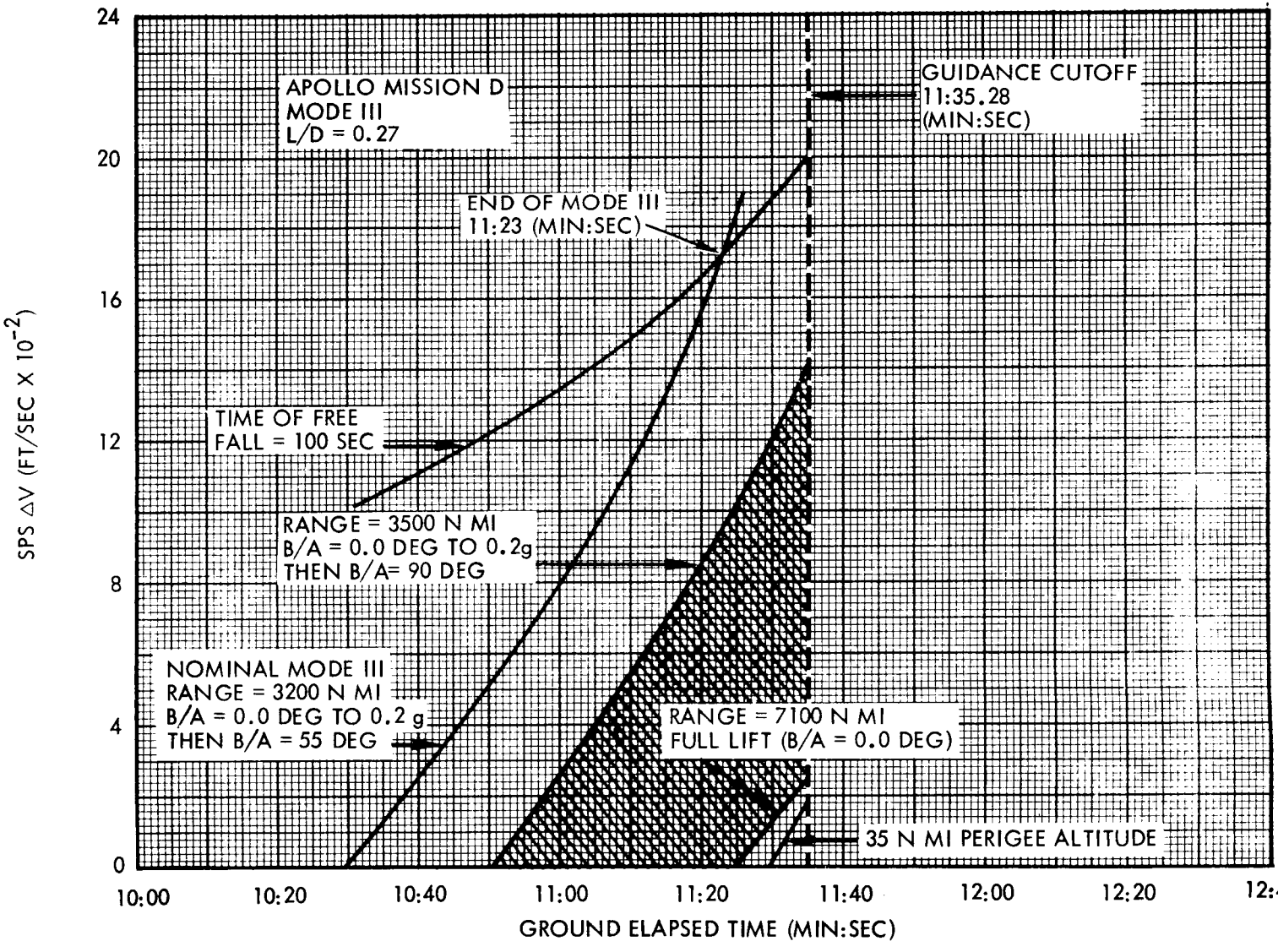


Figure 24. SPS ΔV Required to Perform Nominal Mode III, Zero-lift Entry to 3500 Nautical Miles, Full-lift Entry to 7100 Nautical Miles, 35-Nautical Mile Perigee, and Time of Free Fall Equal to 100 Seconds

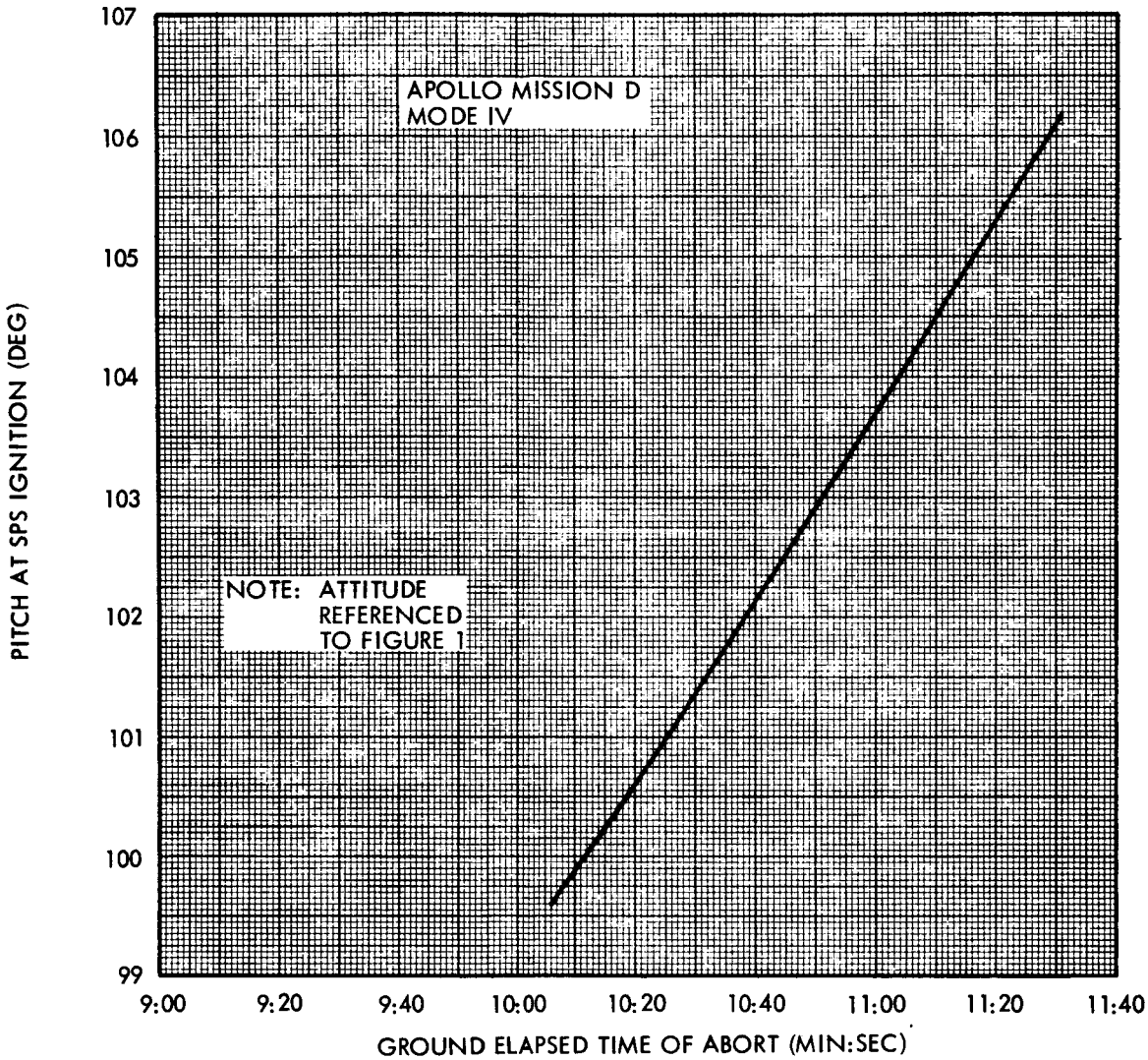


Figure 25. Spacecraft Pitch Attitude at SPS Ignition versus Ground Elapsed Time of Abort for Mode IV

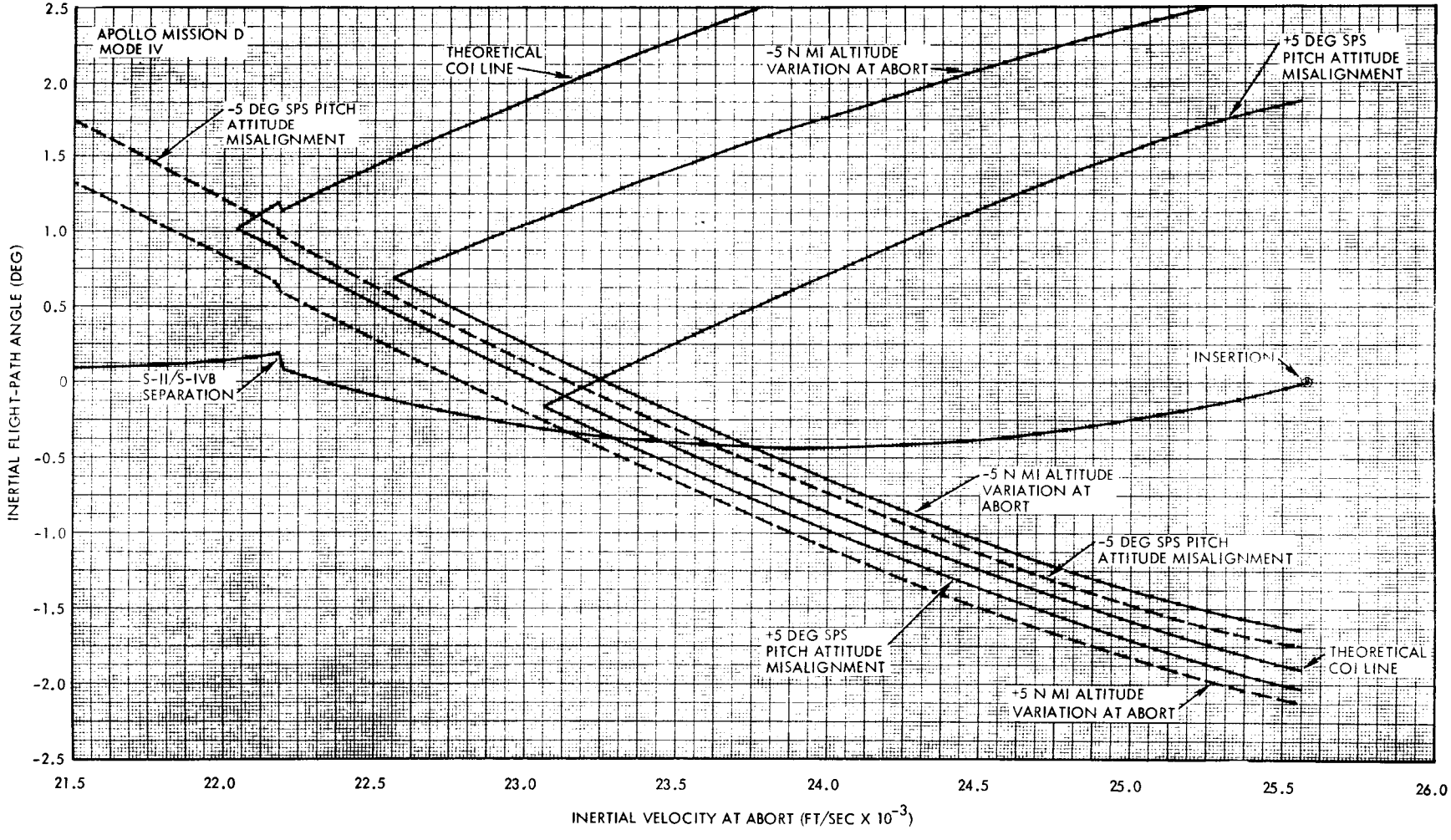


Figure 26. The Theoretical Contingency Orbit Insertion Regime and the Effects of Plus and Minus 5-Nautical Mile Altitude Errors at Abort and the Effects of Plus and Minus 5-Degree Pitch Attitude Misalignments at SPS Ignition

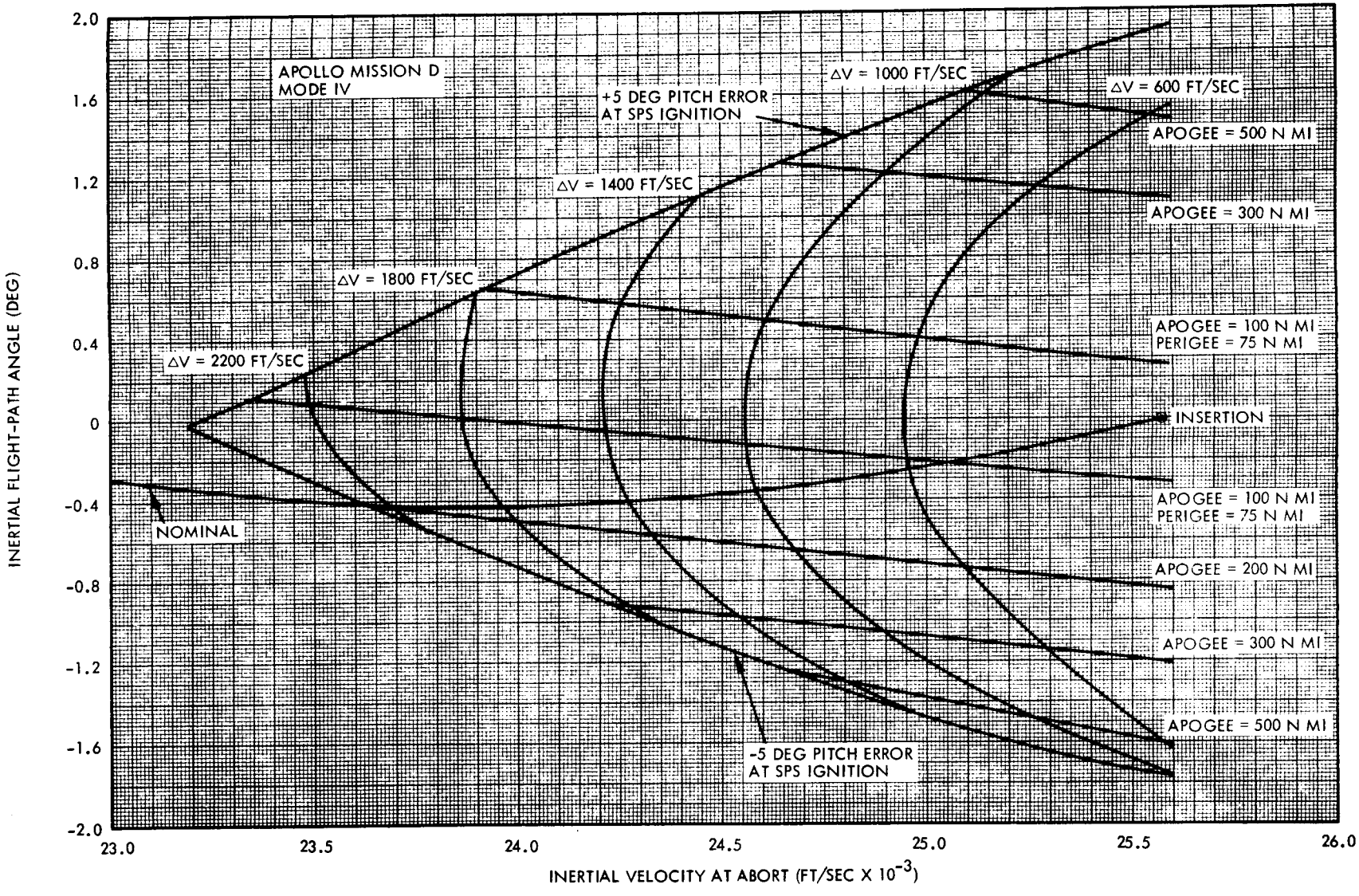


Figure 27. The Contingency Insertion Region Defined by Plus and Minus 5-Degree Pitch Errors at SPS Ignition, and Constant SPS ΔV and Apogee Lines Assuming Correct Pitch at SPS Ignition

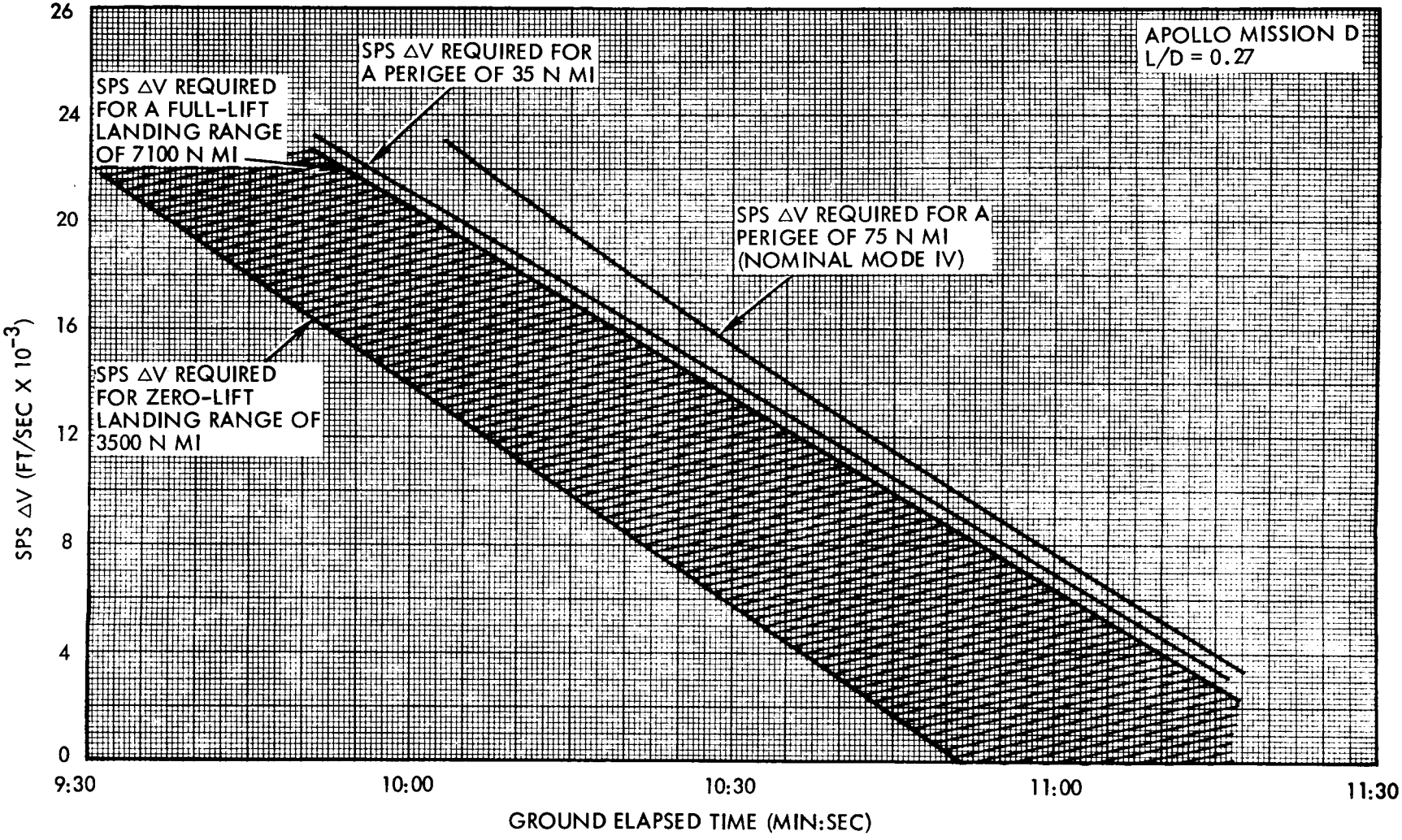


Figure 28. Posigrade SPS ΔV Required for a Zero-lift Entry to 3500 Nautical Miles, a Full-lift Entry to 7100 Nautical Miles, a Perigee of 35 Nautical Miles, and a Perigee of 75 Nautical Miles for SPS Failures During Contingency Orbit Insertion Maneuver

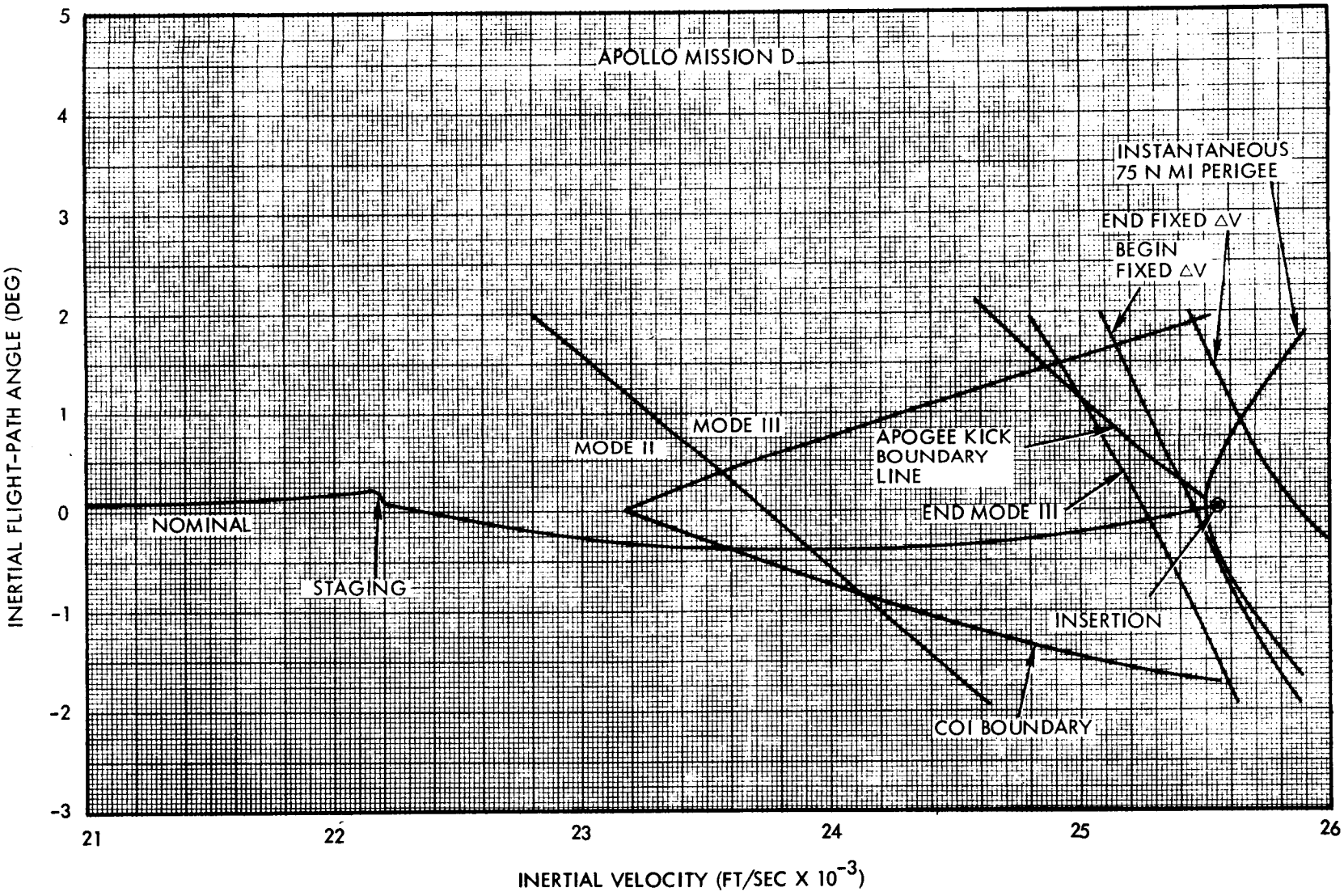


Figure 29. Pictorial View of the Near Insertion Regime Showing the Various Launch Abort Regions on an Inertial Velocity versus Inertial Flight-path Angle Plot

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